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AN IMPROVED DYNAMOMETER.

By WILLIAM P. TATHAM.

The FRANKLIN INSTITUTE JOURNAL for November, 1881, contains a description of a belt dynanometer involving the application of a new principle. Two forms of the machine were described and illustrated and a third form briefly indicated.

This third form has been developed and a dynanometer has been constructed for the use of the Franklin Institute, as represented in the annexed print from a gelatine plate produced by the beautiful photographic process employed by Mr. F. Gutekunst of this city.

This machine consists of a double gallows frame constructed of wood, framed together at the foot and sustaining at the top a cross block, from which the scale beam is suspended. This beam (by Fairbanks & Co.) is of bright steel, capable of weighing 300 lbs. and graduated to 25 lbs. by pounds and tenths, the pound marks being ·95 inch apart.

When the indicator is employed, a spring balance is attached near to the extreme end of the beam so as to exhibit 25 lbs. by pounds and tenths.

From the principal centre of the beam to the extreme right hand

end is 32¼ inches, measuring on the print 1⅞ inches. The scale of the print (where applicable) is therefore 1 to 17·2.

On each side of the principal centre of the beam and 1·9 inches therefrom (unseen in the print) are knife edges, from which hang two links suspending the free moving ends of two cast iron lever frames, whose fulcrums are outside knife edges, which rest upon two iron plates bolted to the gallows frames.

Each of these lever frames carries a pulley, whose face is 7 inches and circumference 27$\frac{3}{32}$ inches high and 27 inches low (measured by a thin steel tape) from which we deduce the average radius of 4·30375 inches.

The axis of the pulley is placed 8·78 inches from the link knife edge and 4·39 inches from a line joining the fulcrum knife edges. The effective radius of the pulley is found by experiment to be 4·387256 inches.

The middle pulley, partially obscured by the counter and indicator card, represents the machine on trial.

Its shaft (diminished) is produced towards the observer, and by means of a clutch and sleeve carrying a small spur wheel and worm screw, the counter and card are put in, or out of gear at pleasure. The shaft, produced towards the rear, carries an outside pulley and may be coupled directly to the machine on trial, or connected with it by a belt.

The middle pulley has a face of 7 inches and a circumference of of 38¾ inches high and 38$\frac{7}{16}$ inches low, or an average circumference of 38·59375 inches. Careful measurements showed that the actual delivery of belt per revolution was 39·595 inches, or about ·005 inch less than the 3·3 feet desired.

The larger lower pulley is the driver on the first motion shaft. It is about 30 inches diameter and 7 inches face. It is on a shaft which receives power from an outside source, and runs in journals on a frame, adjusted vertically in slides, by means of set-screws, so as to tighten the belt.

The belt is about 16 feet long, 6 inches wide, $\frac{2}{3}$ of an inch thick, of oak-tanned leather. The splices are scarfed, glued and riveted, so as to preserve a uniform thickness.

The flesh side of the belt is next the driving pulley and next the two idler pulleys on the lever frames, and the hair side is next the upper middle pulley.

The belt runs in the direction of the arrows on the outside, down on the left and up on the right. But in describing its operation, it is best to follow the tension of the belt in a direction contrary to the motion of the belt itself.

The tension, originating at the lower driving wheel, acts vertically upon the left hand idler pulley at the extremity of its effective radius and in a line joining the two knife edges of the fulcrum, and therefore the effect of this part of the belt upon the scale beam is *nil*.

Losing enough force to overcome the friction of the idler pulley, the remaining tension acts vertically; *first*, by reaction upon the lever frame carrying the idler pulley, at a point corresponding to the extremity of the inside effective radius of the pulley, and thence through the link, upon the positive side of the scale beam; and *second*, upon the middle pulley representing the machine on trial. These forces are equal and opposite.

The tension, acting upon the middle pulley, there performs the work which is to be measured and is reduced thereby. The remainder acts, *first*, by reaction on the middle pulley, and *second*, directly upon the lever frame carrying the right hand idler pulley as before, and thence through the link to the negative side of the scale beam. These two forces are equal and opposite.

The tension then passes over the idler through the fulcrum, as before, to the place of beginning. The outside slack tension has therefore no influence on the scale beam.

It is evident from this description that the only forces bearing upon the scale beam are the tension of the tight belt on the positive side of the beam and the tension of the slack belt on the negative side. The scale beam therefore weighs the difference between the two.

To estimate the power absorbed by the machine on trial, multiply the number of pounds exhibited by the scale beam, by the number of revolutions of the middle pulley exhibited by the counter, and divide the product by 10,000. The result is horse-power and decimals.

The principal centre of the scale beam is lengthened towards the observer, and at its nearest extremity carries a vertical lever arm attached to a horizontal link connecting it with a long vertical index lever, which carries a pencil at its lower end, moving horizontally as the end of the beam vibrates vertically. This pencil marks upon a a ribbon of paper, caused to move vertically between two revolving rollers, which are driven by the worm screw upon the prolongation of

the shaft of the middle pulley before mentioned. One hundred revolutions of this worm cause one revolution of the worm wheel upon one of the rollers.

The scale beam being attached to a spring balance when the indicator is used, the ordinates of the curve traced by the pencil, plus the weights hanging on the scale beam, will represent the force employed, while the abscissas will represent the motion.

Of course, the line traced by the pencil will be a zigzag. As far as this results from the nature of the spring and from variable resistance, it is inevitable. But it also results from imperfections of belts and pulleys, which may be avoided. If the pulleys are perfectly round and balanced, and if the belts are perfectly even in thickness and quality, so much of the trembling will be avoided that there will be no necessity for a dash-pot.

It is easy to ascertain the tension of the belt. By hooking up the lever frame and pulley carrying the slack belt and taking off the link, the tension of the tight side is shown on the scale beam.

It has been stated that the fulcrums of the lever frames are distant from the axis of the pulleys . . . 4·39 inches, and that the effective radius of the pulleys, as determined by experiment, was . . . 4·387256

Showing a displacement of the fulcrums of . ·002744 inches.

This displacement as a cause of error will only act upon the frictions of the two idler pulleys and in the same sense, that is to say, upon the sum of the frictions. Assuming this sum to be 10 lbs. the resulting error on the scale beam would be

$$\frac{6 \times \cdot 002744}{8 \cdot 78} \text{ lbs.} = \cdot 00187 \text{ lbs. or about 13 grains too much.}$$

The experiments for determining the effective radius of the pulleys show some interesting results.

To determine where to place the fulcrum knife-edges on the lever frames, one of the pulleys was fastened in a frame arranged as a lever of the first order, with a knife-edge fulcrum in the axis of the pulley. A piece of belt was attached to the frame, and passing over the pulley, sustained a tray for weights. At the other end of the frame, and at a given distance from the axis, was a knife-edge, from which was suspended another tray. From 50 to 500 pounds were put in the first tray and balancing weights in the second. Then, having two known

weights and one known distance, the other distance was determined in each case with the following results:

Let W be the weight on belt at a distance, l, from fulcrum;
w the weight on frame at a distance, L, from fulcrum;
then $l = \frac{w\,L}{W}$, the distance required.

Weight on the Belt.	Effective Radius. Hair Side next Pulley.	Flesh Side next Pulley.
50 lbs.	4·4666	4·4021
100 "	4·4666	4 4010
150 "	4·4854	4.4102
200 "	4·4727	4·4072
250 "	4·4795	4·4110
300 "	4·4737	4·4182
350 "	4·4850	4·4171
400 "	4·4747	4·4102
450 "	4·4720	4·4075
500 "	4·4827	4·4118
Average, . . .	4·47589	4·40963
Mean radius of pulley,	4·30375	4·30375
Gain, . . .	·17214	·10588

The above table, which is believed to be comparatively correct, shows that the increased tension of the belt (within the limits of elasticity) does not influence the effective radius of the pulley.

After the knife-edges were placed, and the whole tested by suspended weights, it was found that the fulcrums were too far out, and they were all readjusted. After adjustment, the effective radius of the pulley was found to be

	With Flesh Side next Pulley.	Hair Side next Pulley.
	4·387	4·473
Mean radius, . .	4·304	4·304
Gain, ...	·083	·169

To determine the size of the middle pulley, to measure 3·3 feet per revolution, a frame was made to carry two revolving pulleys on parallel shafts, and the belt of the dynanometer was stretched over them. The length of the middle of the belt was measured by bringing all parts of it successively to the straight stretch. Then about a mile of belt

was run over the pulleys. The revolutions of the belt and those of the pulleys were counted and the length of belt per each revolution calculated, with the following results:

$$\frac{\text{No. of revolutions of belt} \times \text{length of belt}}{\text{No. of revolutions of pulley}} = \text{length of belt per revolution of pulley.}$$

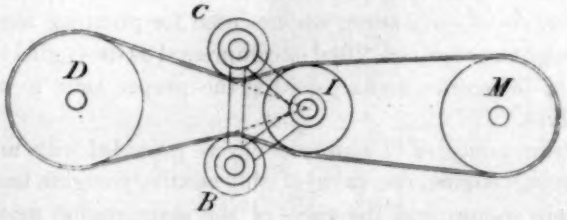
Mean Circumference of Pulley.	Length of Belt per Revolution of Pulley.					
	Flesh Side next to Pulley.			Hair Side next to Pulley.		
	Length of Belt.	Gain.		Length of Belt.	Gain.	
		In Circum.	In Radius.		In Circum.	In Radius.
44 in. (flat)	44·609	·609	·097	44·778	·778	·124
75in.(high)	75·473	·473	·075	75·845	·845	·134

The middle pulley was made from these data, and was found too large, and was reduced four times and tried, with the following results:

Mean Circumference of Pulley.	Length of Belt per Revolution of Pulley.					
	Flesh Side next to Pulley.			Hair Side next to Pulley.		
	Length of Belt.	Gain		Length of Belt.	Gain.	
		In Circum.	In Radius.		In Circum.	In Radius.
38·805	.....	.....	.....	39·792	·987	·157
38·672	.....	.....	.....	39·665	·993	·158
38·641	39·28	·639	·102	39·659	1·018	·162
38·594	.....	.....	.....	39·595	1·001	·159

The last measurement was made with extreme care, and indicates a delivery of belt per revolution of pulley of ·005 inch *less* than the 3·3 feet desired. The tension on the belts was 190 pounds.

The principle of this dynamometer may be usefully applied to test the power conveyed by a belt running from a driving to a driven pulley in position. The apparatus would be somewhat similar in appearance to the transmission dynamometer described by Professor Thompson in the JOURNAL OF THE FRANKLIN INSTITUTE for February, 1881.



D is the driving pulley and *M* the driven pulley. The pulleys *I*, *C* and *B* preserve their relative position, being all upon one frame, which has liberty to revolve around the axis of *I*, held stationary. The belts leading to and from *D* have no influence to revolve the frame so long as they point through this axis. The belts leading to and from *M* will always tend to revolve it with a moment due to the difference of their tensions acting upon the effective radius of *I*. This difference can be weighed.

This arrangement has these advantages over the form described by Professor Thompson: (1) The pulley *I* need not equal either *D* or *M*; (2) The desired position of the belts leading from *D* towards the centre of *I* can be easily determined by a line or straight edge; (3) The result obtained would not be tainted with the friction of either pulley.

The dynamometer has been made without charge to the Institute, the Isaac P. Morris Machine Co. supplying the pulleys, shafts, bearings and cast-iron frames, and Messrs. Fairbanks & Co. all the scale work —both free.

THE ISOCHRONAL WORTHINGTON PUMPING ENGINE.

By J. K. Maxwell.

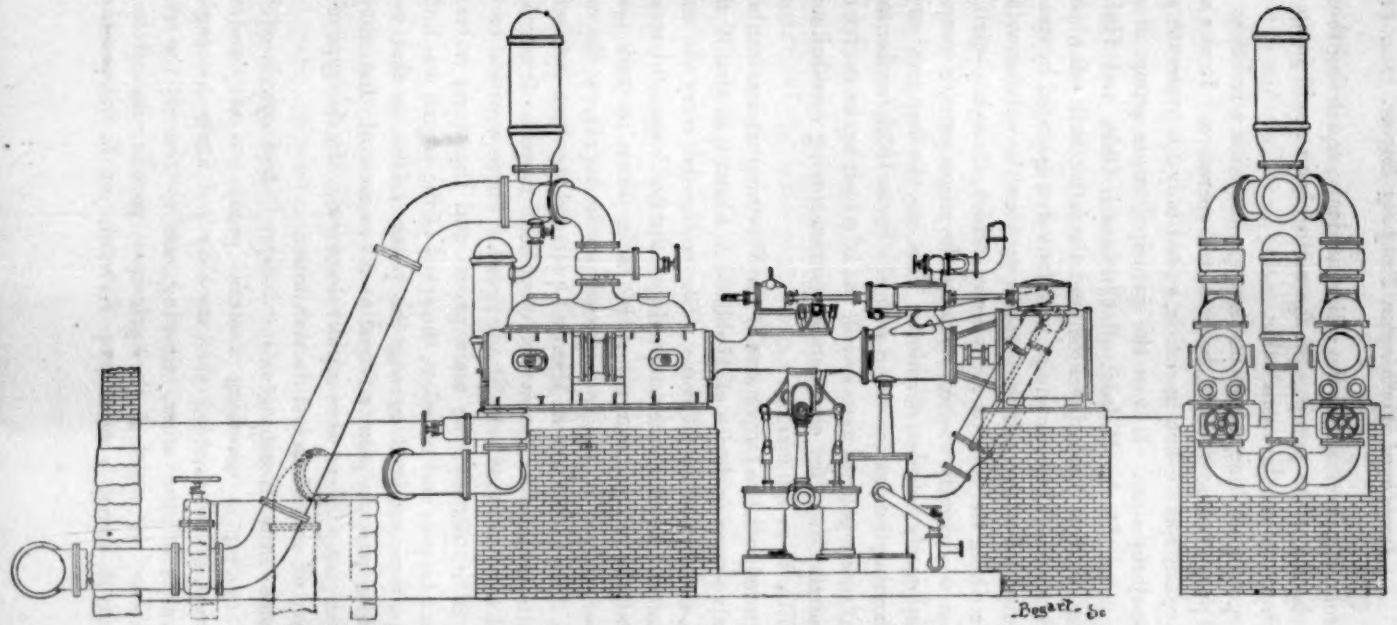
The steam pump is of recent origin, and has just now, by the expiration of the principal patents covering its essential parts, become an article of commerce, in the manufacture and sale of which the public may enter without let or hindrance. As the first steam engines were used for pumping, it is necessary to explain the difference between those and the "steam pump," which can be best understood by stating that the valves of early steam engines used for pumping were operated by bob weights, or springs, lifted or compressed as the engine approached the end of its stroke, and released at the proper time to reverse the steam valves.

The steam pump of the present day is provided with an auxiliary valve-moving engine, the valve of this auxiliary engine being moved by the main engine, and the valve of the main engine moved by the auxiliary engine without the assistance of the momentum of the main engine, the falling of weights, the compression of springs, or releasing of latches of any kind; all its motions being produced by steam direct from the boiler.

Some manufacturers use tappets, so arranged that at rapid speeds the momentum of the main piston assists in moving the main valve, while at slow speeds the auxiliary engine alone performs that office.

There is no record as to the origin of the idea of using one engine to move the valve of another. It was probably thought of soon after engines were made to move their own valves. The first record we have of such an arrangement was in a patent issued in England, to Dixon, in 1837, in which he mentioned two, three or four engines as being so placed that the valve of each could be operated by its neighbor. About 1830 Mr. Penn used a small pump piston and steam piston on the same rod, the valves of the engine being operated by a spring and latch. But little more was done in that direction until Worthington took up the subject, and after considerable labor produced what was called the "Baker & Worthington Jumper," which consisted of a steam piston and pump plunger on opposite ends of the same rod, and a tappet arm projecting from the middle upward, to engage with collars on the valve rod of the engine. The pump plunger worked through a central collar, and when it came near the end of

THE ISOCHRONAL WORTHINGTON PUMPING ENGINE.



Vertical Section of Duplex or Separate-acting Compound Condensing Engine.

the stroke it passed out of the collar suddenly, equalizing the pressure on each end of the pump. So the main piston would jump forward enough to reverse the main valve.

In such a machine it was necessary to establish a resisting pressure in the pump before it could become self-operative. It was useful in its day, but was violent in action, suited only for moderate pressures and medium sizes. It was the principal steam pump in use until 1855, when C. A. Wilson, of Cincinnati, Ohio, and Hubbard & Conant, of New York, invented, and the latter took out a patent for, the first successful steam pump, with its valve operated by steam alone, and provided with cushion ports to prevent the valve-moving piston from striking the ends of its cylinder, which, though a small addition to what was already known, rendered the steam pump a comparatively safe and nearly noiseless machine. This was the first great step toward popularizing the modern steam pump. From 1855, for fourteen years, a great many patents were issued, out of which ten or twelve machines became the basis for considerable manufacturing establishments, and are still sold in the market.

In nearly all, the tappet arm of the Worthington was combined with the valve-moving device of Hubbard & Conant, so that if the latter failed the former would come to the rescue and carry the valve over the ports. A. S. Cameron produced the first successful steam pump without the tappet arm, using the main piston to push open small exhaust valves at the end of each stroke to reverse the main slide valve. In 1866 Cope & Maxwell patented the first successful steam pump operating its steam valve without tappets of any kind. It would work without noise at any speed. There were but two moving parts in it, namely, the main piston and the steam valve. Being without tappets and noiseless, the speed of the engine was limited only by the time required to seat the pump valves, so that very small machines were frequently forced to do more work than they should, and the pump valves were rapidly destroyed. In this type of machine rapidity of action reached its maximum.

About 1859 Worthington's "Jumper" had convinced him that rapid motion in reversing a steam pump was very destructive of its parts, so he doubled the machine and made one engine move the valve of the other, allowing one to rest at the end while the other is making the principal part of its stroke, which, though it seems a small step forward, yet in its practical appli-

cation its effect is almost marvelous. As an artificial means of producing an even flow of water through pipes it has no equal; its effect is superior to any number of pistons driven by cranks arranged on a rotating disk. It is commonly called the Duplex Engine, and is extensively used for waterworks and other heavy pumping. By an improvement adopted by Allison, and subsequently added to by Cope & Maxwell, the same quiet action is obtained in the single pumping engine. A piston attached to the main slide valve, working in a cylinder filled with fluid, with a stop cock in the channel leading from one end to the other, causes the slide valve to move slowly across its ports. The slide valve being provided with the proper lap, produces a pause at the end of the stroke, preventing a sudden reversal, giving quiet action. By arranging the water cushion cylinder on a lever operated by the main engine, and moving in a direction opposite to that of the main slide valve, which is forced along by the auxiliary engine with constant energy, and the resistance being increased through the cushion cylinder by the velocity of the main piston, the main slide valve opens until the main piston acquires sufficient velocity for the two forces to neutralize each other. Then it remains stationary while the piston velocity is constant. If the piston attempts to move quicker it will close the main valve, if slower it will open wider. It is a speed governor, controlling all parts of each stroke, independent of the load on the main engine. It is called the Isochronal Engine, as its piston moves through equal spaces in equal times. By combining the double engine of Worthington with the Isochronal feature of Cope & Maxwell the greatest safety and the most perfect action thus far attained in the direct-acting engine is secured. From the above-mentioned peculiarities it is named the "Isochronal Worthington Pumping Engine."

These engines are of the direct-acting, compound-condensing type, and are fitted with steam-moved valves, controlled by Cope & Maxwell's patent regulator or governor, whereby each machine is accurately controlled under any conditions of service, being in fact an ever watchful and never tiring engineer. The engines are combined and arranged so that each may be run singly if desired; or, in a moment's time they may be changed to work as duplex machines; engine No. 1 controlling its own main slide-valves through its governor, moves the auxiliary slide-valve of engine No. 2, to admit steam to move its main slide-valve; while engine No. 2 controls its own main slide-valves through

its governor, and moves the auxiliary slide-valve of engine No. 1 to admit steam to move its main slide-valve, thus keeping up a continuous plunger action and flow of water from the pumps. Each engine has an independent condenser and two air-pumps, the latter being operated from the rock shaft that gives motion to the governor or regulator cylinder.

The pumps are of the plunger variety, with packing-boxes in the middle, between the valve chambers, which admits of the packing being tightened up while the pumps are in motion. The pump-valves are easily accessible for inspection by the removal of a single cap at each end of the pump chambers. Ample air and vacuum vessels are provided, as are also shut-off valves for the suction and discharge pipes of each pump.

EXPLOSIVE AND DANGEROUS DUSTS.

By Prof. T. W. Tobin, C.E., Ph.D.,
Of the Polytechnic Society, Kentucky.

[An address delivered before "The Fire Underwriters' Association of the Northwest," at the Thirteenth Regular Meeting, held at the Grand Pacific Hotel, Chicago, September 6, 1882.]

During the month of May last I was honored with an invitation to address the Kentucky Millers' Association on "Flour Explosions." Being a subject in which I had for many years been interested, I cheerfully undertook the preparation of a lecture, with illustrations. The experiments, although not new, for chemists well know the combustible nature of organic dust in a finely divided condition, yet so impressed my audience that I was more than repaid, on my part, in their interest and applause for the small amount of labor expended. In preparing that lecture there appeared to me certain conditions governing the combustible state of flour which hitherto had been passed by in investigating the appalling catastrophes that from time to time befall our national industries, in the form of mill fires and explosions. Many of my suggestions, the outgrowth of subsequent experiments, have been received with favor; and my theories, if such I may presume to term them, have had the endorsement of practical men before whom they have found their way. The desire to prosecute the

truth, which is implanted in every scientific mind, has led me further, and I am here to report progress and court your criticism.

Dust Under the Microscope.—Let us together then retrace the narrative of these researches. I will first call into requisition that wonderful instrument that science plunges into the mysterious and opens out its inner secrets to the light of day—the microscope. As it would be difficult to show you individually the objects that I shall employ as illustrations, I made careful drawings and photographs of them, and by means of a powerful oxyhydrogen light will project magnified images of these upon the disk now before you. (*The lecture room was here darkened and the subsequent microscopic illustrations shown on a screen, magnified to many million times the size of their originals.*)

1. I take first some ordinary flour, commonly known as "*Graham meal*," and we find that it consists of quite a miscellaneous gathering of various bodies. There are present: (1), the skins of the wheat-berry; (2), the hairs or "beard;" (3), cells of gluten, a waxlike substance, being the most nutritious portion of the grain; and lastly, (4), the starch in various sized granules. This body forms the bulk of ordinary flour and flour-dust. Now, in order to understand intelligently the natural placement of these parts of the wheat grain, I will bring magnified images of that body.

2. This shows: (1), the beard; (2), the skins, three in number, that enclose the internal starch or gluten; (3), at the bottom there will be noticed the germ, and contiguous with it the crease. Now, the first operation of the miller who has recourse to the newer processes of reduction, is to clean by brushing or agitation, the whole surface of the grain for subsequent operations, and 2d, to break open this crease and get rid of the germ and incidental impurities that are usually there. In so doing a small amount of flour is made, but being charged with impurities, is blown into the dust-room. There are then two classes of dust: 1st, wheat dust, obtained from cleaning the surface of the grain, and 2d, the refuse flour dust discarded, because being mixed with germ and other foreign matter. Although in my investigations I found two separate channels and outlets, the character and condition of both classes of dust therein were almost identical in physical properties.

3. This will show by a section of the grain the disposition of the parts already described.

4. Pure starch granules, as found in "arrowroot." This may be taken as the typical element in flour dust. We mark the compact spheroidal form of the granule. At a temperature of 140°F. in water it swells, bursts and is converted into the well-known pasty mass used in the arts. In common with most organic matter, starch is combustible, and contains normally about 18 per cent. of water.*

This amount varies, and exposed to a dry atmosphere, may be considerably reduced. I take it as a rational deduction that the most rapid combustion of flour, attended with explosive violence, would occur when freed from moisture. The individual granules burst simultaneously, and the disturbance thus produced bringing new supplies of oxygen, would instantly determine the rapid consumption by fire of the entire mass. This fact will be discussed further on.

5. Immediately following the starch granules we have a quantity of dust obtained from the club moss, called "lycopodium." It is the seed or spore of that plant. Notice the near resemblance in size and structure to the starch granule; but it differs in one respect in being of an oily nature, which (as our experiments will presently convince us), renders it very inflammable.

6. This is highly bolted flour, and as the microscope shows, freed from the husk, the beard, and even the gluten of the wheat, leaving nearly pure starch. We observe that there are three distinct qualities of the granule; (1), the giant; (2), the medium, and (3), the farina, or starch powder.

7. This view will give a fair idea of what change takes place in starch on submitting it to a heat of over 140°; in other words, it is cooked flour. The granules have all disappeared, and in their place are irregular masses of amorphous "dough" or "paste."

8. Some dust collected from the "wheat dust room" shows starch, husk, fractured gluten cells, the beard, and other impurities; it also contains, generally, "fungi," or "smut." The dry and oily nature of this dust renders it more inflammable than starch.

9. Wood abrasions from an axe-handle factory, showing the fibrous and cellular texture of the minute particles of dust. This material is inflammable owing to its extreme dryness.

Combustion.—I will now as briefly as possible lay down the principles that are generally acknowledged by chemists as underlying the phenomena of combustion in organic bodies and apply them to the

* Miller's Elements of Chemistry.

special instances under consideration. The substances which we will deal with to-night consist of three elements; oxygen, hydrogen and carbon. Although in variable quantities the oxygen and hydrogen are always in the ratio of water, *i. e.*, eight parts by weight of the former to every one part of the latter; heat is capable of determining their union and water is the result. Carbon or charcoal is thus left, and being incapable of existing in any but a solid condition, soon stifles further combustion. If, however, oxygen be added, either from the air or as a gas, perfect consumption of the body takes place. We know that a piece of wood, if an insufficient supply of air is present, can only become charred by the most intense heat known. This is the first principle that I will now endeavor to illustrate.

Experimental Demonstration.—Here is some hydrogen in a tube; it is very much the same as that burning from the lamps in the room. I plunge a lighted taper into it, and the taper is incapable of burning for lack of oxygen or air. Hydrogen, although a highly combustible body, will prevent combustion, and even suffocate this burning taper. I now add some air, neither in itself explosive nor combustible, and then heating the mixture, I get a deafening report. Beyond all question, I have generated an explosive body.

Then I will take some flour, and perhaps I should tell you that, like the hydrogen when free from free oxygen or air, it is incombustible. Flour thrown on the glowing furnace will retard and even, if sufficient in quantity, extinguish the fierce fire. Like hydrogen alone, it is a non-supporter of combustion. Observe, I plunge a burning taper in this measure of flour, and, as you would predict, the taper goes out. Here is a substance, chlorate of potash, which is very rich in oxygen, and I cannot alone make it burn, as you may see. Two harmless bodies I mix; the essentials of combustion are supplied and brilliant fire is the result. Oxygen gas, always present in the air, an exceedingly active and corrosive body, is then the one thing needed to render these inert bodies combustible, and even explosive.

Moisture.—Water, in all its forms, is opposed to combustion, and its presence modifies the rapidity with which the consumption takes place. It is, I think, hardly necessary to illustrate this as a general principle, although in the sequel we shall find in it an element of great importance.

Now, it is by these simple principles that combustion in its varied phases, from the slow decomposition and decay of the green vegetable

to the explosion of the modern flour mill, is governed. By the modification of them I think I can show you some interesting results.

Wood Dust.—Here is some dust from an axe-factory. It was obtained and has been preserved in a dry state. By means of a simple piece of apparatus I cause it to be blown about and thoroughly mixed with air. A flame is near it, rapid combustion takes place, and a column of fire of intense heat leaps up in the air, six or seven feet high.

Flour Dust.—This sack contains ordinary flour. Previous to the lecture some of it was placed in a drying oven and submitted to gentle heat. By this time much of the moisture usually contained in flour has been expelled; one condition has been filled to make the substance combustible. I next comply with the other and mix it with air. See the result! Mark the violence attending the combustion.

You may seem astonished, and ask whether this is flour alone. Yes; from the same sack I use some more: this time not with the same and result, for it is damp and the air cannot mix sufficiently to render it even inflammable.

Then we arrive at a very important conclusion. The violence of combustion is the inverse of the moisture of the dust experimented upon.

Other Dust.—We will now put the testimony received so far to the torture of further investigation. I have some lycopodium. You remember its near resemblance to flour dust under the microscope. It is not necessary to dry this as we did the flour, for it is protected by an oily waterproof coat and moisture cannot enter it, but it requires air, for I plunge a lighted taper into its midst, and, as in other instances, neither will the powder burn nor will the taper. I urge some of it through the heated flame with this unexpected result: an all-devouring, an explosive column of fire.

Explosion.—The results obtained so far convince us that dust is inflammable in degree according to its dryness. No actual explosion has yet been obtained in our experiments. Perhaps it will be well to define the term explosion since there has been objection raised to its use in connection with flour combustion by some writers whose opinion is worthy of respect. It almost seems ridiculous to imagine anyone looking at the disaster at Minneapolis, could so pervert the English language as to say that no "flour explosion" took place. Our dictionaries give us the definition of the word "to drive or burst out with a loud report or violence." Hitherto we have not then complied with

this definition and therefore had no explosion. Let us see if it is possible to obtain explosion, and by what means. When dry organic dust is heated to the point of ignition, the oxygen and hydrogen first combine to form water. Intense heat is thereby generated, and this heat acts in two ways: first, to char and finally convert the carbon into carbon dioxide gas; and, secondly, to expand the surrounding air. The gas and the heated air occupy considerably more space than in their first state, and the more rapidly these results are achieved the more nearly will the act approach the violence of explosion. The air then plays as important a part as the dust, and should the air space be confined, but insufficient to restrain its force of expansion, explosion in the full sense of the term takes place.

Explosion, Intensity of Combustion.—We can trace the various degrees of combustion in the many mill and factory fires that have been placed on record. Notably amongst them I will call your attention to two—the terrible disaster of Minneapolis, which occurred May 2, 1878, and the Hecker mill fire in New York, July 31, 1882. In the former we may reasonably infer that the air was dry and the dust pretty generally diffused throughout its entire extent, owing to the long continued and busy period the mill had been taxed with work. The wheat of that year, we are told, was hard and dry, and at the time of the explosion, 7.20 P. M., the air was chilly and the windows and openings generally closed. Here are conditions for explosion. In the latter I will take the testimony of the superintendent, Mr. J. V. Hecker, as recently given before the fire marshal of New York. He says: "The fire originated in the 'smutter' on the seventh floor. 'Smutters' are considered the most dangerous parts of the machinery of a mill, on account of the friction which may be produced by any foreign substance getting in and striking fire between the revolving cylinder and the case surrounding it. These cylinders were of stone and the cases of chilled iron. The smutters make from 250 to 300 revolutions per minute. The dust is sucked from under the smutters and forced by a fan into the (wheat) dust room through a spout about ten inches square. I think the fire was caused by a spark struck by friction in the smutters, igniting the dust and passing through the spout into the dust room and igniting the dust therein." That an explosion did not then occur, as in many other instances was, I take it, owing to the fact that while the air in the mill was charged with fine dust the dryness was sufficient to cause the flames to spread with

lightning-like rapidity through the entire building, making the 500 workmen run for their lives. There was insufficient moisture to allow the dust to burn with the violence characteristic of an explosion. From the meteorological record of that day I find the barometer stood at 30·42, temperature, 82°F., and there was 82 per cent. moisture in the air, with cloudy sky. Thirty per cent. of humidity that day, in all probability, saved the nation from a disaster far more terrible than happened in Minneapolis, or since the history of milling has been recorded.

Many other illustrations might be taken which would find an intermediate place in the degrees of intensity of combustion. You will call to mind the candy-works explosion in the same city some years ago that was an explosion of starch. The Ehret Brewery in August, 1881, experienced an explosion from the barley used in malting. Barley, in common with wheat and other cereals, consists principally of starch, and no difficulty is experienced in accounting for that phenomenon. The Pullman Car Works, at Detroit, 1880, had an explosien of dust in the spout used for conveying shavings from various portions of the factory to a place near the furnace. This spout is the counterpart of the dust room of the flour mill.

Conditions of Explosion.—We will now proceed with our experiments and see if we can cause those substances which hitherto have shown themselves as highly combustible, to become explosive. We will confine the air space and see the result. For that purpose I have before you a simple piece of apparatus which, for a better name, we will call a dust or flour gun. It consists of a hollow shaft about seven feet high. At the top is a hopper, which by means of a paper cover I can close; at the bottom is a gas pipe to which is attached a Bunsen burner. By means of a trigger arranged near the top I can cause a fine shower of dust to descend and fill the shaft. When the first portion of it reaches the flame and the shaft is filled with dust, ignition takes place and the entire column burns. It is necessary that there should be a plentiful supply of air. This is provided for in numerous perforations about the walls of the machine. If the dust is now dry we have all the conditions for explosive combustion. Let us proceed:

I place some lycopodium and turn the trigger. The top is blown off and takes fire, so intense is the heat. Here is some wheat dust from the dust shaft of a flour mill. The result is much the same,

only less in degree, and yet sufficiently illustrates the principles we have discussed.

THE WET BULB HYGROMETER.—Before proceeding further in our subject it is necessary that we should understand the construction and use of an instrument that will play an important part in the subsequent line of thought I purpose now leading you. It is known by the modest title of "Wet Bulb Hygrometer," and its mission is easily related.

Its indications tell us that the atmosphere about us on the clearest and brightest day or night contains a large amount of water dissolved in it; that this watery vapor or gas is very transient in its nature, but that very seldom is the air fully charged, and never is moisture entirely absent. When the air has as much water as it can possibly hold we call it saturated, and in that condition we say it has one hundred per cent. of humidity. Cold air requires less moisture to saturate it than warm air, hence elevation of temperature means increase of the saturating point.

It tells us that there is a constant variation going on—sometimes at short intervals, and at others in long periods; and it further shows, as we are ready to anticipate, that there is a constant change in the capacity of the air and amount of moisture in it during the twenty-four hours of each day. As I take it, this atmospheric property plays an important part in our investigation of dust combustion.

In various localities the average capacity of the air varies considerably. "In the North American Continent," says Ganot in his admirable text-book on physics, "where the southwest winds blow over large tracts of land, the relative moisture is less than in Europe; evaporation is here far more rapid; clothes dry quickly, bread soon becomes hard; newly built houses can be at once inhabited; European pianos soon give way here, while American ones are very durable on the other side of the Atlantic. As regards the animal economy the liquids evaporate more rapidly, by which the circulation and the assimilation is accelerated and the whole character is more nervous. In some parts of East Africa, on the other hand, the air is so charged with humidity that paper becomes soft and sloppy from the loss of its glaze, and gunpowder, if not hermetically sealed, refuses to ignite." As a suggestive thought incidentally to these statements—are not the greater number of mill explosions in districts over which a dry atmosphere is known generally to exist? By the indications of this instru-

ment we find regular changes during the day, there being maxima about 8 A.M. and 8 P.M., and minima about 3 A.M. and 3 P.M. The Signal Service record (Louisville) for a few days will suffice to show this fact:

	6.25 A.M.	10.25 A.M.	2.25 P.M.	6.25 P.M.	10.25 P.M.
Aug. 1,	90	79	59	72	88
Aug. 2,	82	62	51	61	85
Aug. 3,	90	67	57	90	93

CONSTRUCTION.—The instrument in construction is simple, consisting of two delicate thermometers, one of which is kept saturated by a reservoir of water. As the air loses or gains in capacity to dissolve moisture evaporation takes place from the wet instrument. Proportionate to the capacity of the air to contain water will be the degree of evaporation, and the extent of evaporation is indicated by the lowering of temperature. Thus, by a very easily constructed table, showing the difference of temperature readings of the two thermometers, a pretty accurate estimate may be made of the amount of water necessary to produce saturation and the amount already contained therein. The instrument may be easily constructed or purchased for a few dollars at any first-class optician's. It should, however, be accurately adjusted and the scales properly constructed. I will not occupy your time in explaining further how the readings are made, as that information may be obtained from any good text-book on meteorology, but will at once proceed to detail records arrived at by its aid in my subsequent description.

MILL FIRES.—The principles I have heretofore laid down, simple as they may appear, I felt convinced underlaid many of the fires and terrible explosions so disastrous to flour mills, and to their ignorance I conceived might be attributed at least some of the most awful catastrophes chronicled in our industries. Every year, to his sorrow, the mill-owner finds his risk of destruction of property and life growing greater, and I believe to-day there are insurance companies that would as soon grant a policy upon a gunpowder magazine or dynamite factory as to the proprietor of a flour mill. I determined to submit these principles to a rigid test. Accordingly, with hygrometer and note book in hand, and the valuable co-operation of Mr. Chas. Ballard, a

practical miller, I penetrated every crevice and chamber, from basement to roof, of one of the best-ordered mills in the country.*

I will not occupy your time in describing the various parts of an ordinary flour mill, but make use of the technical terms applied to the various localities. Suffice it to say that the mill in queston has every modern improvement in milling machinery, is substantially constructed of brick, is run by steam power and well ventilated from all sides. The grain is received in the basement; the first floor is devoted to gradual reduction mills, and the second and third floors to bolting machinery and purifiers of the most approved description. It has a capacity of 180 barrels per day.

Mathematics cannot err; mark, now, the extraordinary records:

Record of Temperature and Humidity of the Atmosphere at the Flour Mill of Messrs. Jones, Ballard & Ballard, Louisville, Ky., August, 1882.

Date.		External.		Internal Humidity.			Weather.
Day.	Hour.	Temperature.	Humidity.	Grinding Floor.	Bolting Floor.	Dust Shaft.	
Aug. 10....	11 A.M.	70°	52 P. C.	67 P. C.	54 P. C.	.....	Clear.
Aug. 11...	12 M.	80°	51 "	62 "	65 "	.....	Fair.
Aug. 12...	3 P.M.	82°	45 "	60 "	53 "	.....	Fair.
Aug. 14..	3 "	89°	53 "	54 "	53 "	43 P. C.	Fair.
Aug. 15...	1 "	81°	87 "	83 "	83 "	60 "	Rain.
Aug 16...	1 "	82°	83 "	87 "	87 "	63 "	Rain.
Aug. 17...	3 "	79°	57 "	64 "	64 "	53 "	Clear.
Aug. 18...	3 "	83°	48 "	52 "	52 "	38 "	Clear.
Aug. 19...	2 "	78°	50 "	55 "	58 "	41 "	Fair.

The first unexpected result we notice in these records is that the atmosphere in both grinding and bolting rooms is moister than the air outside. On closer examination I soon discovered the cause of this.

* This mill is situated in Louisville, Ky., and owned by Messrs. Jones, Ballard & Ballard.

Each set of rollers used in reducing the grain, 22 in all, was heated, owing to the friction and resistance in crushing. By the heat thus generated the normal moisture of the wheat was continuously being evaporated, and escaped into the mill; the spouts near the rollers were bedewed with moisture and the flour doughed. Notwithstanding that the windows on all sides were open, and the ventilation as thorough as possible, the entire atmosphere of the mill was thus kept in a moist condition.

After carefully examining the purifiers, bolting chambers, wheat cleaners and other machinery for the dangerous element of dry air, I came lastly to the dust shafts. As I have already stated, in this mill there are two of these—one used for collecting the dust from the wheat cleaning, which is carried to the basement and there collected in a dust room; the other carries off the light refuse flour dust made in the first reduction of the grain. In making observations I found the amount of moisture in both these shafts, and the various parts of each one, differ so slightly that I did not deem it desirable to note the variation.

The Dust Shaft.—Could science speak plainer to us than in these facts? Recall the many mill fires and explosions that periodically visit us, and does not each narrative begin with the now easily interpreted incident, that destruction commenced at the dust shaft or in its vicinity? Here, month after month, streams of dry air, drier than the hot summer breezes, are urged with the velocity of a storm, depriving the wood and other combustible matter of its moisture, converting all that will burn into tinder-like fuel, dry air separating and buoying up the particles of drier dust until the fatal spark occurs and combustion ensues, with the explosive violence, alas! too well known now to need description.

I do not hold that mills are blown up by the dust alone in the shafts, but I do believe that the fires generally originate there, and the local explosion caused thereby is often sufficient to fill the entire atmosphere of a mill with lodged and loose dust. A second charge is thus prepared for combustion, and the grand explosion occurs.

Dust shafts are then danger centres. Can there be any longer doubt in your minds? Is it necessary for me to suggest that they should be well protected and solidly constructed? Dry air in a mill, I am inclined to think, is little less dangerous than coal gas escaping in the air. Why make these shafts of light match boarding? Will you longer, in face of these deductions, use gauze and canvas doors com-

municating with them and your mills? As I stood one day near by one of these doors my hygrometer showed the dangerous enemy stealing into the dust-charged atmosphere of the mill.

Having accepted the fact, which I take for granted is now settled in your minds, that the dust spouts and flour shafts are drier than the surrounding atmosphere, let us see if science can explain why this should be so. Nearly all dusts are well known to chemists to be hygroscopic in their character. Flour especially will divest moisture from the air. But we have seen also that in the process of grinding, by the heat generated in friction, a large amount of the normal moisture of the grain is driven off and the subsequent heated flour must necessarily be abnormally deficient in water. The percentage of moisture in the dust shafts would be, of course, governed by the humidity of the external atmosphere, as we find it shown in the table set forth.

THE BAROMETER.—There is another interesting relation between the dust and the atmosphere as its medium, which is at least worthy of a passing remark. Do you know that dust is sometimes lighter than at other times? More correctly, the atmosphere, in its variable density, causes the light particles of floating matter to become more or less buoyant. Let me illustrate the statement by a familiar incident: Have you not noticed at some times, generally on a dry day, how the smoke rising from the chimney will rise and be buoyed up in an almost vertical direction—how on those days the very dust in the roads hangs about and refuses to settle? The barometer on these occasions will be high, showing that the air is dense. Another day the air will be charged with moisture; the smoke hangs about the ground, no dust in the air now, for the air is too light to buoy it up; the barometer is low and rain is probable. Is it only reasonable to infer that during a high barometer the lighter particles of flour are reluctant to settle, and, floating in the air, add to the many dangers of a flour mill? I make this brief allusion to a probable cause conducive to fire and explosion. Time will permit me to do no more.

DEDUCTIONS.—Gentlemen, the accurate diagnosis of disease points to a line of remedy. Have we not enough information on the cause of dust explosion to suggest a mode of remedy? It may be that we have not yet gone to the bottom of the mysteries involved, but we have, I think, indications enough to adopt a line of treatment.

Let me, as I have presumed so far, in the interest of science suggest:

1. That dust rooms are dangerous centres, and should be built, if possible, of brick, as you would build a smoke stack, and all communicating shafts and doors be of sheet metal.

2. That, as in the long period of drought in summer nature moistens the dry forest with rain and dew, so our parching winds, constantly blown through shoots, shafts and dust rooms, should be daily, if practicable, charged with vapor or steam.

3. Keep the mill free from superfluous dust and flour.

4. As dry air is the miller's enemy, let him learn to use the hygrometer, and on its indications adopt methods, as he may think best, to drive it from the many lurking places in his mill.

5. In dry weather, when the air is dense and thick with floating particles, let him not overwork or strain the capacity of production. Overtaxing work has often preceded disaster.

6. Never use open lights in the mill if it is possible to avoid them, and get as much ventilation as possible.

Conclusion.—Before concluding the subject I have attempted to lay before you, the cause of events makes it necessary to add one more record. After I had formed the line of thought and made observations at Messrs. Ballard & Co.'s mill, an incident occurred that riveted my interest, as I think it will yours. After hunting nature to the utmost limits of investigation, I was rewarded beyond measure in an occurrence which took place unexpectedly to all, but unfortunately for my friends in labor, the Messrs. Ballard.

When lecturing before the Millers' Association of Kentucky I made the following remarks: "Could we have had a register of the state of the atmosphere in the unfortunate Washburn mill, Minneapolis, immediately preceding the explosion, I doubt not that it would have shown a marked absence of humidity." Science has permitted me to realize this, for on Aug. 22d my closing record at the mill reads:

Date.	Hour.	External.		Interior.	Weather.
		Temperature.	Humidity.		
Aug. 22.	11 A.M.	82°	60	Wheat dust shaft and adjoining bin on bolting floor now in flames. Fire confined to upper portion of shaft, but fierce and destructive.	Fair.

What originated the fire I pass uncommented upon. The fact that the dust shaft burned with rapidity, and that the entire mill was but a wreck from either the flames or explosion, I leave for your thoughtful consideration. On the spot where I had made my observation, in the wheat dust room, the last time I visited the building, there remained only the ruins of property estimated from eight to ten thousand dollars.

ECONOMICAL STEAM POWER.

By William Barnet Le Van.

[A paper read by title at the Stated Meeting of the Franklin Institute, Oct. 18, 1882.]

Up to this point I have spoken of the engine only, and now I propose to investigate boilers and their adjuncts. A few years ago fifty pounds per square inch was thought a high pressure of steam to use in mills, but of late years pressures of seventy-five and one hundred pounds, and even one hundred and twenty pounds per square inch have become common. I predict that the day is not far distant when one hundred and fifty and two hundred pounds per square inch will not be uncommon.

The efficiency of a steam boiler is measured by the number of pounds of water it will evaporate into dry steam by the combustion of one pound of coal, compared with its cost; that is to say, the quantity of steam produced for its first cost and the least total cost for running it.

The thirty years experience of the writer is to the effect that the deficiency of a large number of good boilers in producing steam economically is due solely to their imperfect brick settings, flue connections and improper proportioning of grate surface to heating surface. To make them good, economical steam generators a resetting of their brick work is all that is required.

To illustrate: Some years ago a large manufacturer in this city consulted the writer in regard to the great quantity of coal consumed under his boilers. On making an examination it was found that the chimney and main flue were all right, but about thirty square feet of the most effective heating surface of each boiler, immediately over the fire grate, were rendered practically useless from being enclosed in brick work.

There being five boilers in all, the loss of effective heating surface amounted to about one hundred and fifty square feet of direct radiant heating surface.

The consumption of coal being twenty-five tons per day, this enclosed heating surface over the fire bars was a matter of great importance, as it is well known by experienced boiler engineers that *each square foot* of heating surface, above the fire bars, is equal to *ten square feet* of heat transmitting power in the flues; and these boilers having tubular flues the extent of the loss may be readily seen. I would state that these boilers were designed and built, and also set in brick work, according to the plans and specifications of one of the largest and most successful firms in this city. The owner of the establishment was a gentleman of education and intelligence, and when I brought the matter before him and explained what alterations were necessary in order to reduce the coal consumption, and the reason therefor, and that the only remedy lay in the resetting of the boilers, he was at once satisfied and ordered them reset.

The boilers were altered under my directions and the result was a better quality of steam and a saving of *five tons of coal per day*, at a cost of *five dollars per ton*, or *twenty-five dollars per day*, that is, *twenty per cent.* of the total consumption of coal.

At the Centennial Exhibition the greatest care was taken in the brick settings of the boilers for trial, and the results showed how well the extra outlay was repaid; the lowest evaporation in horizontal tubular boilers being 10,216 *pounds* of water evaporated, at 212 degrees, per pound of combustible.

In the writer's opinion steam boilers, as now constructed, can be very little improved on; but in regard to their brick settings and flue connections there is a large field for improvement, especially in the construction of the *combustion chamber*, which should be so arranged that combustion of the gases started in the furnace may be completed before they escape into the chimney.

Combustion Chamber.

The ordinary combustion chamber is invariably made too small, both in height and width.

The general proportions allowed are so limited as to give it rather the character of a *large* conduit, whose only function should be to allow the combustible gases to *pass through* it, rather than that of *a*

chamber in which a series of consecutive chemical processes are to be conducted. Such furnaces, by their diminished areas, have also this injurious tendency—that they increase the already too great rapidity of the current through them. The defect of insufficient capacity in the chamber of the furnace, *above the fuel*, will be best appreciated when we consider that in it the gases are generated, their constituents separated, each brought into contact with the oxygen of the air, and finally their combustion effected.

The practice of constructing furnace chambers so shallow, and with such inadequate capacity, appears to have arisen from the idea that the nearer the body to be heated was brought to the source of heat the greater would be the quantity received. This is no doubt true when we present a body to be heated in front of a fire. When, however, the approach of the colder body will have the direct effect of interfering with the process of nature (as in gaseous combustion) it must manifestly be injurious. *Absolute contact* with flame should be avoided where the object is to *obtain all the heat* which could be produced by combustion of the entire constituents of the fuel.

Dr. Ure observes: "When a boiler is set over a fire its bottom should not be set too near the grate lest it refrigerate the flame and prevent that vivid combustion of the fuel so essential to the maximum production of heat by its means. The evil influence of leaving too little room *between the grate and the boiler* may be illustrated by a very simple experiment. If a small copper or porcelain capsule containing water be held over the flame of a candle, a little above its apex, the flame will suffer no abatement of brightness or size, but will continue to keep the water briskly boiling. If the capsule be now lowered *into the middle of the flame* this will immediately lose its brightness, becoming dull and smoky, covering the bottom of the capsule with soot, and owing to the imperfect combustion, though the water is now surrounded by the flame, its ebullition will cease."

When, however, the object is merely to raise a body to a high temperature, by local application, as when we heat a bar of iron in a blacksmith fire, or a flame, and without reference to the quantity of heat produced and wasted, indirect contact becomes necessary.

So much, however, has the supposed value of near approach, and even contact, prevailed that we often find the space over the fire grate about twelve inches deep, and behind the bridge wall, frequently but

a few inches deep, so as to bring the flame in contact with the boiler, as shown in Fig. 1.

As a general rule, deduced from practice, it may be stated that the depth between the grate bars and the bottom of the boiler should not be less than twenty inches where the grate is but four feet long, increasing in the same ratio where the length is greater; and secondly, that the depth below the grate bars should not be less than twenty inches, although this depth is not so essential.

The forming of combustion chambers back of the bridge wall, extending down below the grate bar to the level of the ash-pit, is a

Fig. 1.

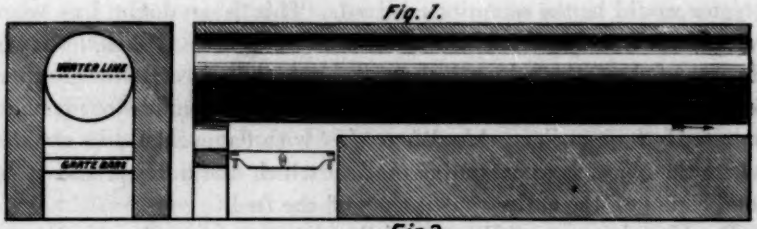
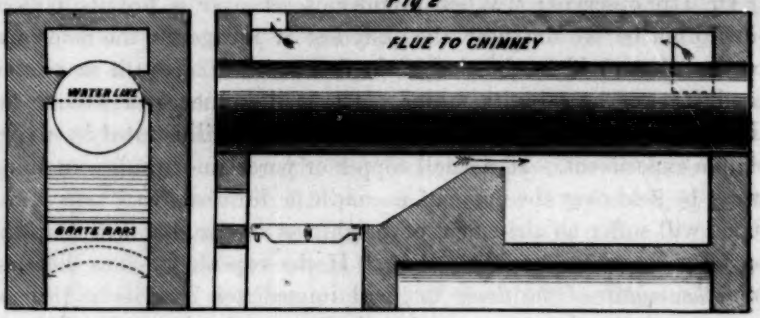


Fig 2



source of great loss of heat, especially if the sub-soil is damp. (The experiments of Professor Tyndall revealed the astounding fact that the power of aqueous vapor, at the pressure of the atmosphere, to absorb heat is six thousand times greater than that of dry air.) Or, in other words, damp air loses heat by radiation in the proportion of seventy to one of dry air, as heat is absorbed by moisture in addition to the radiation of the walls surrounding the chamber.

The writer lately reset a plain cylinder boiler having a chamber open to the ground floor back of the bridge wall. This chamber the writer arched over, about eighteen inches from the bottom, and the

result was a saving in coal of about *ten per cent.* These air chambers are non-radiators. Professor Tyndall's experiments on this subject have clearly demonstrated that *dry air* is absolutely non-radiant.

In another case, four plain cylinder boilers, set on the same plan as that just described and having the grate bars but fourteen inches from the bottom of the boilers, were reset by raising the boilers twenty-four inches above the grate bars and arching over the combustion chambers back of the bridge wall, and also forming a flue along each side of the boilers, of about four inches wide, up to the top of the water line. (See Fig. 2.)

The result was, that while *seven tons* of coal per day was burnt before the resetting, the coal consumption after resetting was reduced to five tons. My latest practice is to form a flue so as to return the products of combustion over the top of the boiler, as also shown in Fig. 2, thereby to a great extent reduce the steam down to nearly dew point.

The ordinary furnace, as generally built, does not allow sufficient space for a complete mixing of the gases, and although the air admitted, due to imperfect fitting of the doors, mixes with the gases, the temperature of the mixture is not high enough for ignition, and the gases pass off unconsumed.

By increasing the distance between the bottom of the boiler and the grate bars and carrying a moderately thick and hot fire, with a rapid draft, and a proper admission of heated air above the grate bars and a thorough mixture of the gases evolved, with the hot air admitted, perfect combustion can be attained.

The admission of air above the bars is on the same principle as the flame from a Bunsen burner. This flame, as every one knows, is almost colorless, and is never used for giving out light; but from the intimate mixture of air and gas, produced before ignition, it is intensely hot. In fact, the radiation of a flame is to a great extent due to heated, unconsumed solids and dense gases, and when, as in Bunsen's burner, a proper amount of *hot* air is supplied to an ordinary coal gas flame, these dense particles are consumed the combustion being complete.

That it is the presence of dense gases which gives luminosity to a flame has been shown by numerous authorities. On increasing the pressure of the gases burnt the luminosity is greatly increased, and candles burn with less light at the top than at the bottom of a moun-

tain. If the ordinary candle be lighted on the top of a high mountain it will be found that the candle loses, by burning, as much of its own weight, in a given time, as if it were burned at sea level. In respect to its luminosity, however, it is the mere shadow of what it is at low altitude, in fact, it burns more like a spirit lamp.

It has been determined, experimentally, that carbon, in burning from the solid condition to carbonic acid, generates 14,500 units of heat, or 100 pounds of water from 67° to the boiling point, or converts 15 pounds of water, at 212°, into steam, or lifts 11,194,000 pounds one foot high, and carbon, in burning to form carbonic oxide, generates 4452 units. That is to say, one pound of carbon, in burning to form carbonic acid, generates heat sufficient to raise 14,500 pounds of water one degree. If, then, it generates 14,500 units of heat in burning to carbonic acid, and only 4452 units of heat in burning to carbonic oxide, it follows that carbonic oxide, containing one pound of carbon, would generate in burning to carbonic acid 10,048 units, so that carbon in burning through its first stage to carbonic oxide gives off only about *thirty per cent.* of that which it gives off in completely burning through both the first and second stages to carbonic acid. (Hydrogen in burning to form water generates 62,000 units of heat.)

We thus see the necessity of admitting a sufficient supply of air to the coal when burning, not allowing any of it to escape in the form of carbonic oxide and thus doing away with the prodigious unnecessary waste, which takes place when carbonic oxide is allowed to burn in or at the top of the chimney instead of in the furnace or combustion chamber.

We often see flame coming out of the top of a chimney, especially those of river steamers; this is chiefly carbonic oxide which is burning, not the flame of the fire below which reaches up to that height. Whenever carbonic oxide is so formed, the coal is being burnt at a great loss, as a great quantity of the heating power is being sent up the chimney.

Dynamical Value of Combustion.

The unit of heat being one pound of water at 39°Fahrenheit raised one degree Fahr. in temperature, and the mechanical equivalent of this heat being 772 foot-pounds, the dynamic value of the combustion of one pound of gaseous hydrogen is

$$62{,}000 \times 772 = 47{,}864{,}000 \text{ foot-pounds.}$$

So that if it were possible to convert the whole of this heat into available power, the combustion of one pound of hydrogen gas per hour would develop a force equal to

$$\frac{46{,}864{,}000}{33{,}000 \times 60} = 24 \text{ horse-power,}$$

and as a pound of solid carbon in burning to carbonic acid develops work equal to

$$14{,}500 \times 772 = 11{,}194{,}000 \text{ foot-pounds,}$$

the combustion of one pound per hour would, therefore, in a perfect engine, exert a force of

$$\frac{11{,}194{,}000}{33{,}000 \times 60} = 5{\cdot}5 \text{ horse-power,}$$

the standard horse-power being taken at 33,000 pounds raised one foot high per minute,

$$33{,}000 \times 60 = 1{,}980{,}000 \text{ pounds per hour.}$$

Now take the amount of coal consumed by one of our best automatic steam engines in general use in our factories, averaging two hundred indicated horse-power per hour and burning six thousand pounds of coal per day of ten hours run.

This would be equivalent to a consumption of six hundred pounds of coal per hour, and the consumption per indicated horse-power would be

$$\frac{600}{200} = 3 \text{ pounds of coal per hour.}$$

The average anthracite coal as delivered at the factory boiler-house contains, in round numbers, about eighty-five per cent. of carbon. If we neglect the other constituents, we may consider that instead of burning three pounds of coal per hour per indicated horse-power, we are burning eighty-five per cent. of three pounds, or about two and one-half pounds of pure carbon.

We are therefore generating

$$14{,}500 \times 2{\cdot}5 = 36{,}250 \text{ heat units}$$

and getting in exchange *one indicated horse-power.*

As before shown, one unit of heat is equivalent to 772 pounds raised one foot high and, therefore, 36,250 heat units are equivalent to

$$11{,}194{,}000 \times 2{\cdot}5 = 27{,}985{,}000 \text{ foot-pounds.}$$

This shows that we are burning coal sufficient to raise 27,985,000

foot-pounds, or fourteen horse-power, and are actually only raising 1,980,000 foot-pounds or one horse-power. Or, in other words, we are, in fact, only getting out of a first-class steam engine about *one-fourteenth* of the power we should do.

This shows also how important it is to have the combustion chamber properly arranged so as to burn the fuel to carbonic acid.

Economical Combustion.

Coal may be said to be consumed with the greatest possible economy when the whole of the carbon enters into combustion with no more air than is necessary to supply the combining oxygen. The best condition of combustion is the contact of carbon with oxygen and the presence of a high igniting temperature. To maintain a high temperature in the furnace, the combustion or chemical combination should be complete before any heat is abstracted from the gases. There should be no smoke, but simply superheated gaseous vapor, carbonic acid and nitrogen. The quantity of this last would then depend solely upon the thoroughness of the admixture of the combustible gases, so that each atom of carbon might come into contact with the requisite atoms of oxygen. When the atoms have combined, they should be removed as directly as possible, as their presence prevents the combustion of the unconsumed remainder. The best practical arrangements for effecting economical combustion are a furnace composed of a non-conducting material and a rapid draft through and about the burning coal. A furnace composed wholly of fire-brick is preferable, but other considerations frequently preclude its adoption.

The course of the current of air through the furnace should not be too direct nor its volume too compact. But the admixture of the gases will be better promoted if the air be admitted through a series of small jets into the combustion chamber, and if the current of gases be diverted from side to side by suitable obstructions placed in the furnace.

As boilers are now generally set in brickwork, the greater part of the air for combustion is generally admitted into the furnace through the grate-bars. The air-spaces between the bars must, therefore, be kept clear of clinker, ashes, etc., by the free use of the slicing-bar. It is of great importance, also, that the layer of coal upon the grate-bars should not be too thick, or the air will be unable to pass up through it, and it is also necessary that the depth of coal be of uni-

form thickness, otherwise a large quantity of air will be drawn in at the thin places and none at the thick, thus leading to the production of a large quantity of carbonic oxide which, although invisible, nevertheless contains partly unconsumed carbon.

With a properly constructed combustion chamber under the boiler, with air admissions above the grate-bars, the fire-door will not be required to be opened as often as a boiler set to receive its air supply through the bars only; as in the former a thicker layer of coal can be carried and less slicing will be required, thus producing less clinker, as the air admission is not obstructed by ashes and clinker. For, as a rule, the fewer times the fire-door is opened the better; not that the introduction of the coal in large quantities is to be recsmmended, but because each time the furnace door is opened there is a rush of cold air into the furnace, which tends to cool the combustion chamber and to bring on leakage of the boiler seams from the contraction arising from cooling.

Air Admissions.

As to *the* place for the admission of the air, a large number of experiments show that so far as effect is concerned it is a matter of indifference in what part of the furnace or flue it is introduced, provided the one essential condition is maintained of keeping the temperature of the fuel gases above the temperature of ignition. This temperature, according to Sir Humphry Davy, should not be under 800 degrees Fahrenheit, since below that flame cannot be produced or sustained. This, in fact, is the basis of protection in the miners' safety lamp. In practice, the air has been introduced at all *parts of the furnace and with equally good effect*. Its admission through a plate distributor at the back of the bridge and at the door end effected all that could be desired.

To raise the temperature of the air supply is my practice up to the point of ignition. I recommend the construction of a double passage or air-flue in the brickwork on each side of the furnace, by which the air drawn in at the front passes the whole length of the side walls and back again to the fire, where it is delivered upon the fuel at a high temperature, having in its journey through the hot bricks become considerably increased in volume, due to its absorption of heat, so that it becomes an actual *hot blast* upon the coals, and the result altogether is a very perfect combustion of the coal and a total absence of all smoke in the use of bituminous coal, logwood cuttings, spent tan, etc.

Grate Surface.

The area of the grate surface should be proportional to the quantity of coal which is to be burnt upon it in an hour, and the height of the chimney, taken in connection with the temperature of the heated gases, determines the *rate of combustion* per square foot of grate.

The grate should bear a certain proportion to the section of chimney, which is about 8 to 1.

Heating the Feed Water.

The ordinary temperature of feed water is about 60 degrees Fahrenheit, and at this temperature the *heat* required to generate a pound of steam is

$$180 - 60 = 120 \text{ units of heat.}$$

By using the *heat* of the exhaust steam to raise the temperature of the feed water, a very large saving is effected. The temperature thus attainable is limited by that of the exhaust steam, with non-condensing engines from 140° to 200° with a well-constructed heater. With condensing engines the feed water is usually taken from the condenser at about 100° by which means about 40 units of heat per pound of steam are saved.

With non-condensing engines, having a good heater for the feed water to pass through, the latter can be raised to 200°Fahr., producing a saving of at least 50 units of heat per pound of steam.

This is not the only advantage gained from the use of hot feed water, as at 200°Fahr. much of the solid impurity in ordinary water is deposited in the heater in place of being passed into the boiler, where its deposition retards the transfer of *heat* and lessens the efficiency of the boiler. By heating the feed water and thus reducing the *heat* per pound of steam, a higher efficiency may be produced from a given boiler, owing to the less rate of transmission per unit of heating surface.

The Water Supply for Boilers.

The feed water should be put into the boiler as hot as possible and at a point *near* the *surface* of the water inside the boiler. The cold water descends, but before reaching the bottom it will have become heated, thus keeping the boiler at an even temperature. If the water pumped in be low in temperature it should be well distributed through a perforated pipe in the mass of water in the boiler and not allowed

to impinge on any portion of the metal of the boiler, or it will be liable to crack the plate from continual action of contraction and expansion. Water pumped into the boiler near the bottom does not rise until it becomes heated, and this plan of feeding the boiler tends to keep the bottom of the boiler cooler than the other parts.

The best plan is to have a well-constructed feed-water heater, as its cost is more than balanced by the increased durability of the boilers; and as the feed water is generally heated by the exhaust steam from the engine, which would otherwise be wasted, the difference or saving between using feed water at 70 degrees and say 200 is about *twelve per cent.* of the coal consumed in making steam; or a given weight of coal being used in both cases, about *fifteen per cent.* more effect will be obtained from feed water at two hundred degrees over that of cold water. The heating of feed water amounts to the extension of the heating surface of the boiler, but it has this advantage that the heating surface of the apparatus is kept free from soot while that of the boiler is not. It has been found by experience that each ten degrees of heat so imparted to the water saves one per cent. of fuel.

Temperature of the Escaping Gases.

The temperature of the escaping gases *must* exceed that of the steam in the boiler at least fifty degrees, otherwise there will be a loss by radiation.

Prof. R. H. Thurston says: "The maximum conductivity, or flow of heat, is secured by so designing the boiler as to secure rapid, steady and complete circulation of the water within it, . . . and securing opposite directions of flow for the gases on one side and water on the other."

Chimney.

The most important factor for producing steam economically is the chimney, for on it we depend for the proper combustion of the fuel; for without intense draft perfect combustion cannot be accomplished. The intensity of draft is, however, independent of the size of the chimney, and depends upon the difference in weight of the outside and inside columns of air. This is usually stated in an equivalent column of water, and may vary from zero (0) to possibly two inches in height. It varies directly with the product of the height into the differences of temperature.

The intensity of draft required varies with the kind and condition

of the fuel and the thickness of the fires. Wood requires the least, and fine coal the most. To burn the latter to advantage a draft of about a 1¼ inch of water is necessary, which can be obtained by a well-proportioned chimney, one hundred and fifty feet to two hundred feet high.

A rapid draft is in one respect equivalent to a large fire grate area (the higher the chimney the less area of grate will be required), since it equally enables more fuel to be burned in a given time, and thus increases the power of the boiler in generating steam. A quick draft, however, has this advantage, that, inasmuch as the temperature of the furnace is higher when the same quantity of heat is generated in a small space than it will be when generated in a large space, the heat is transmitted much more rapidly to the water of the boiler in the case of the strong draft, by reason of the higher temperature thus obtained. As there is more heat transmitted in the region of the furnace, in the case of the strong draft, there will be less remaining to be transmitted in the region of the flues; or, in other words, the flues will have less work to do, and they may either be made shorter, or the heat will be more thoroughly absorbed.

A *low* fire is never economical; the same quantity of *fuel* burnt at a *high* temperature would do more work. A chemist will get *fourteen pounds* of water turned into steam by one pound of carbon; but in engineering the most that can be attained is *twelve pounds of water* to steam by one pound of carbon.

Long flues absorb more heat than small, as both the volume and intensity of the heat are greater with equal surfaces. This shows the importance of having a high chimney, in order that smaller flues can be used to produce the same result as larger ones with a corresponding less height of chimney.

The Theory of Chimney Draft.

The upward movement of warm air and gases of combustion in chimneys is caused by the difference in density of the external air and of the enclosed gases. All permanent gases expand 0·0020284 (or $\frac{1}{493}$) of their volume for each degree Fahr. of difference in temperature, and the density in weight per unit of volume decreases as the volume increases; that is, if the volume is doubled the weight per unit of volume will be only one-half of the original weight.

Suppose a parallel tube, *A B*, Fig. 3, to be of one square foot cross-

section and 100 feet high, filled with air of the same density and temperature as that surrounding it; the air pressure will then be in equilibrium in and outside of the tube, namely, 14·7 pounds to the square inch, or 2116·8 pounds to the square foot, which is the pressure at the base, *A*.

All gases exert pressure equally in all directions, so that the downward pressure of the air in the tube at *A* is balanced by the upward pressure of the surrounding air; consequently no motion will ensue.

Fig. 3.

The weight of a cubic foot of dry air at 60° Fahr. is 532 grains; or, the air in the tube (100 cubic feet) would weigh 53,200 grains, or 7·6 pounds. That is to say, the pressure per square foot at the top, *B*, of the tube would be only 2116·8 — 7·6 = 2109·2 pounds, the force with which the enclosed air presses upwards at *B*, and is balanced by the pressure of the air above, so that no motion will ensue.

Now let us heat the air in the tube from 60° to say 360° Fahr., a difference in temperature of 300°. The enclosed volume of air will be expanded to

$$1 + 300 \times 0{\cdot}0020284 = 1{\cdot}60852 \text{ volumes.}$$

The actual volume in the tube is 100 cubic feet expanded to 160·852; that is, 60·852 cubic feet will be ejected from the tube by the force of expansion of the heated air, but the weight of the remaining 100 cubic feet of air in the tube will be only

$$\frac{7{\cdot}6}{1{\cdot}60852} = 4{\cdot}714 \text{ pounds,}$$

or $7{\cdot}6 - 4{\cdot}714 = 2{\cdot}886$ pounds less than the upward pressure of the surrounding air at the base, *A*. The heated air in the tube will consequently be set in motion upwards by this motive force of 2·886 pounds, by the cool air entering under the base, *A*.

This is the principle upon which the so-called "draft" is generated in chimneys, which in reality is no draft, but a pushing of the cold air under the fire-grate, and by expansion of the heated air, which drives the mixed gases of combustion up through the chimney.

In our first illustration the cold air from underneath the tube will soon drive out the heated air and establish an equilibrium of pressure, by which the upward motion is stopped; but in a furnace the enclosed

air and other gases are continually heated, which results in a continual motion upwards in the chimney.

Intensity of Draft.

The intensity of draft is independent of the size, and depends upon the difference in weight of the outside and inside columns of air. The intensity or degree of heat produced by fuel varies in proportion to the rate at which it burns; the greater the draft a greater amount of work will be produced from the same fuel. This goes to show the importance of a high chimney.

Draft of Chimneys.

The *power of the draft* is directly proportioned to the height of the chimney, and the velocity with which the external air flows in to supply the draft depends upon the temperature of the ascending gases. The higher the temperature is the lighter will the gases be, and consequently create a stronger draft through the grate bars. This velocity is proportional to the square root of the height of the chimney.

Air at 520 degrees expands to double its volume at 32°. At this temperature, therefore, within the chimney, the velocity with which the external air will pass through the grate bars would be proportional to the square root of half the height of the chimney, which, expressed in feet per second, is equal to eight times the square root of half the height of the chimney, or

$$V = 8\sqrt{\frac{H}{2}}$$

Example.—The height of a chimney is $H = 128$ feet, and the temperature of the gases $T° = 520°$. What will be the velocity of the air through the grate bars?

$$V = 8\sqrt{\frac{128}{2}} = 64 \text{ feet per second.}$$

As a general rule for calculating the draft at any temperatue, the following is near enough for all practical purposes

$$V = 8\sqrt{H\,a\,(T° - t°)}$$

In which

H = the height of the chimney, in feet.

h = the difference of the height of columns of equal weight.

V = velocity of the escaping gases, in feet.

g = gravity, a constant number = 32·17.

$T°$ = the temperature of the warm air.

$t°$ = the temperature of the cold air.

a = the coefficient of expansion of air for one degree of the thermometer at 32° will be $\frac{1}{493} = 0{\cdot}002028$ under constant pressure.

$h = H\,a\,(T°—t°)$.

Area of a Chimney.

The area of a chimney for ordinary purposes may be determined by the following formula:

$$A = \frac{0{\cdot}3\ \text{HP} + 10}{V\,H} \text{ or } \frac{\square + 10}{V\,H}$$

HP = horse-power of boiler.

A = area of chimney, in square feet, at smallest part.

$\square$ = area of grate, in square feet. The constant 10 allows for the difference in friction between large and small chimneys.

Height and area are the only elements necessary to consider in an ordinary chimney.

Expansion of Gases.

Unlike solids, gases expand equally for an equal increase of temperature, as measured by a thermometer. The experiments made by Rudberg, and confirmed by Regnault, show that atmospheric air, heated from the freezing to the boiling point, expands at the rate of $\frac{1}{493}$ or 0·0020234 for each degree Fahrenheit, being the increase of volume under constant pressure.

If we wish to ascertain the volume of $v = 200$ cubic inches of a gas at $t° = 60°$ would occupy at $T° = 100$ degrees, we must remember that it does not expand $\frac{1}{493}$ of its bulk, at 60° for each degree, but $\frac{1}{493}$ of its bulk at 32°, and so on.

$$V = v\left(\frac{T°—t°}{493} + 1\right) \text{ and } T°—t° = \frac{493\,(V—1)}{V}$$

V and v = volume of dry air of temperature $t°$ and $T°$.

$$V = 200\left(\frac{100—60}{493} + 1\right)$$

THE UNIVERSALITY OF VIBRATIONS.

By C. C. Haskins.

[Read at the meeting of the Chicago Electrical Society, May 15, 1882.]

Vibrations, in the most limited sense of the term, are defined as minute reciprocal motions of the particles of an elastic body when they are thrown out of equilibrium. Oscillations embrace a class of movements which may be termed vibrations of greater dimensions—the two differing only in degree. These may traverse vertical arcs or horizontal curves, parts or the whole of circles or ellipses. Amplified still further, we find movements embracing extended cycles of time, yet ever returning to a former condition or position. These are all, generically speaking, vibrations, differing only in the one element of time. We may go farther and include as vibrations all that class of changes or motions which have the one common similarity of starting at a given point, origin or condition, and having accomplished a change of place, form or position—a cycle of movement or transition—returned to their pristine status; again and again repeating this round of differing phases.

These periodic rounds, whether comprising two or more changes, whether molar or molecular, I have classed as vibrations, and within this scope I include the movements of elastic bodies, springs, chords, gases, etc., the segmental action of suspended bodies like pendulums, the gyratory movements of storms, the progression of planets in their orbits, and those chemical changes which are ever active in nature, producing combinations in the mineral, animal and vegetable world, by which the various conditions of growth and decay so constantly and regularly succeed each other.

These mutations—now noiseless, hardly perceptible in their slow progress, at other times bold, rapid even to instantaneity—eventuate in the same accomplishment, the restoration of the elements to their simplest form and their recombination in the chemical world, in the world of motion—to repeat for all time this round of change, this following in the beaten path of nature's ages—periods of time of which the mind of man can take no cognizance.

Take an example: An internal chemical commotion occurs beneath the crust of the earth's surface. Inharmony among the existing elements as combined results in greatly increasing the volume of these,

and the stored up energy heretofore confined is set free. This energy is expended in the line of least resistance, and the result is an upheaval of the earth's surface. A mountain is born. One limit of the vibration is reached.

Rains descend upon the upheaved surface, penetrate the crevices of the rocks, dissolving and carrying portions of these in solution to lower levels. Winter, with its irresistible frosts, widens the seams in the most obdurate rock-formation, crumbles, and slowly—but surely—reduces them to a comminuted condition where they may again become sedimentary rock, once more to be subject to the will of the great plowman Nature, whose implement is the earthquake, whose furrows are the mountain ranges.

Within the earth, deep hidden from human ken, where the rock-formation is of a nature to permit, huge caves are in progress of formation. Metallic bases, combined with acids, in the form of flakes or nodules, absorb the infiltrating moisture from above, and the acid, having a greater affinity for the alkaline rock than for the metal, leaves the latter and uniting with the former produces a new compound, which, being soluble in water, is carried away in the outgoing current. The metal, too, forming a new combination with the oxygen of the water, is similarly disposed of and a cavity is formed in the bowels of the mountain. Here is the nucleus for a cave. In this way Mammoth Cave was formed; and Nature, tireless designer that she is, is still at work making additions and modern improvements in these her magnificent underground palaces.

The transitions of water are familiar to you all. As rain it descends from the clouds, it penetrates the earth, evaporates, and is again precipitated upon the ground. It may assume the form of ice, or snow, or clouds, or steam—yet it is still water—the two combined elements of its existence are ever present. We may separate these by force and the same force will re-unite them. We may rarify the fluid by heat, or condense it by the withdrawal of that force, but it remains water still. We have added nothing which did not exist before. We have taken away nothing. Thus we may ring all the vibratory changes on any substance in nature. We destroy nothing, we add nothing, and the conditions which wrought former changes and produced previous results will invariably repeat the phenomena in obedience to the unwavering fiat of vibratory law.

Our sulphate of copper batteries give us a fine exemplification of

such changes from an electrical and chemical standpoint. Sulphate of copper, a combination of sulphuric acid and metallic copper, is soluble in water. This forms one of the elements of our battery. Metallic zinc is used for the other. These are placed in water, and the connections being made, which render the circuit complete, the stored up energy of the elements is released, the salt of copper is dissolved, and its component parts, sulphuric acid and metallic copper are separated. The copper, restored to its metallic form, is deposited at the bottom of the jar. The sulphuric acid attacks and combines with the metallic zinc, producing sulphate of zinc, which is held in solution by the water. Now, when the action is continued until the elements are consumed, by evaporating the water and weighing the residuum, we will find just as much copper, and zinc, and acid as originally existed, but the combinations have been altered, and by still farther manipulation we may separate the acid and the zinc, reducing the former to a liquid form, and the latter to its metallic state, and recombine the acid and the copper so as to complete the cycle of vibration and erect a second battery, similar to the former, from the same elements.

Water in motion presents a fine illustration of one form of vibration. If we carefully observe a floating body, a chip, or a bird, on the dead swell of the sea, we shall find that the water motion does not carry the object away from its position, but merely compels it to rise and fall perpendicularly. A rope suspended from one extremity, when shaken, will give us the same wavy motion. The vibratory undulations will run from the one extremity to the other, until overcome by gravity, they cease to be noticeable.

The vibrations of a large body of water, like the sea, are complex and of nearly every degree of amplitude. Not a breath of air passes over it; not a ray of light or heat penetrates it; not a sound is produced at the surface, within or below it, but creates a vibratory movement in the mass. The waves, the tides, the currents, the evaporation, the very color of the sea are as strictly amenable to vibratory law as are the strings of the violin or the pipes of a church organ.

Vegetable life furnishes another familiar illustration of vibratory law—this cycle of existence.

At first the seed, selecting and absorbing the proper nourishment from the surrounding soil, chemically changing the force thus released to its own use, it increases its dimensions, sending certain portions of its organism in search of farther food below the surface, and directing

other members upward until its growth is finished, its mission ended, it first ceases to provide for the continuance of its species, then dies and decays and is returned to the soil and the air from whence it came. It has resolved into its primal elements and completed its vibratory cycle. Yet there are minor vibrations in constant motion during its entire life period, each complete in its own sphere of action; each to an extent a necessity, an element in the grand result.

Within the minute vessels, those veins and arteries that lead from the tiniest rootlet to the uttermost extreme of the highest leaf on the tree, what quantities of life-blood have been carried up from the ground for its sustenance and refreshment. Thousands of hogsheads of water have been transported to the tops of the forest monarch during its years of growth, carrying with them the elements required for the food and growth of the wood, the bark, the leaves and the fruit, in addition to the forced contribution which the atmosphere has been compelled to contribute, and these elements have been appropriated, separated, assigned and assimilated, all in obedience to and by the aid of vibratory law.

The summer's growth, the winter's rest, the ripening and fall of the leaves and fruit, regular as are the seasons, are but so many annual vibrations in its period of existence.

Its various parts, too, are in constant motion, and whether we note the swaying trunk and bending limbs contending with the wintry gale, or the pendulum leaves gently waving in the summer breeze—vibrations in some degree or form are still the same ever present accompaniment of its daily life.

As in the tree, so in the tiny blade of grass. Could we but invent some method of multiplying our hearing capacity in the same degree as the microscope has enlarged the field of human vision, every blade of grass, every clover stalk and daisy stem would roar with the laughing cataracts that rush through the little veins and arteries, and run the mimic mills to feed and paint their gaudy blossoms.

As in vegetable, so in animal existence. Birth, life, death, decay, follow each other to make up the vibration of physical existence with all animate nature. It is difficult to designate a function pertaining to animal life that is beyond the control of these laws. We breathe; respiration is vibratory. Our blood flows in pulsations. All nervous excitation, whatever the sense—sight, hearing, taste, touch; even thought, that highest of all nervous sensations—all these are clearly

vibratory in their action. Why, even our organs of locomotion are but vibratory appendages, like the fins of the fishes or the wings of the feathered world.

A clear conception of distance, beyond a limited range, is difficult of accomplishment. Even comparison with familiar areas or spaces, when applied to extended intervals, gives but unsatisfactory results. By day we behold the sun which lights and warms the earth from a distance of nearly one hundred millions of miles away. By night we behold the lesser lights, the number of which, including the telescopic stars, is estimated at no less than seventy-five millions. Many, very many of these are vastly superior in size to our own sun (which has over one million times the volume of our earth), yet by reason of the great distance of these immense bodies they appear to us as mere points of light.

The dog star (Sirius), the brightest star in the northern heavens, has the volume of sixty of our suns, yet such is its immense distance, about one hundred millions of millions of miles away, its brilliancy is much inferior to that of the planet Venus, which is one-tenth smaller than the earth.

Now, to come back to the sun, the centre of our solar system, we see it surrounded by a series of planets, each performing revolutionary vibrations around it, their cycles of movement varying with their varying masses and distances, and these again in many instances carrying with them secondary bodies, each moving with uniformity the most precise, harmony the most complete, and with a grandeur awe-inspiring.

The planet on which we live has each day since its creation whirled in space, completing its diurnal revolution on its axis, and each year its annual movement about the sun, lighted and warmed by vibratory force from that great luminary, held in its position by vibratory law. And the sun, too, revolving upon its axis in about twenty-five and a half of our days, moves in an orbital track about some other sun, carrying with it the entire system of which it is the centre; and this again is supposed to be a system dependent upon another, and another, until there is no conceivable limit.

It is beyond the grasp of the human mind, until infinity is explainable, until we are enabled to comprehend an existence which has neither beginning nor ending; and all these movements are amenable to gravity, which holds and controls these immense unnumbered masses

in space; that sends them forward on their untiring journeys, over paths without tracks, with an uniformity and exactness to excite a feeling of wonder and admiration in the most skeptical human mind. Yet our own solar system has no mean or insignificant proportions when we consider the extended vibrations of comets in their annual revolutions round our sun.

One of these astronomical puzzles, of which the orbital elements were computed by competent authority, requires no less than 3380 years to complete a single oscillation. When we remember that these wanderers are sometimes accompanied, during a portion of these orbital trips, by an attendant having a lineal measurement greater than the distance from the earth to the sun, we are struck dumb with astonishment and reverence at the immensity of the mechanical movements of these whirling pendulums of God's Eternal Clock.

Everywhere in nature there exists a substance of infinite elasticity and extreme tenuity, which surrounds the atoms and permeates every so-called solid. It fills all space throughout the universe. This substance is known as luminiferous ether. Vibrations from luminous bodies are taken up by it and transmitted by wave motion. Light is conveyed by it something similarly to the manner in which sound is conveyed by air waves with, however, this marked difference: while sound waves move in one direction those of light move at right angles to this—the former being, in scientific language, longitudinal while the latter are transversal. The mechanical properties of this ether are rather those of a solid than of an air.

The vibrations of this extremely tenuous and elastic substance are, from its very nature, capable of inconceivably rapid movements and, from like causes, it is never at rest. The rays of the sun are brought to us at the rate of about 187,000 miles in a second. Sir John Herschel estimated that a cannon ball would require seventeen years to reach the sun, while light requires but eight minutes to traverse the same distance, and that while the swiftest bird would be nearly three weeks in flying around the world, light would make more than the entire distance for each stroke of its wing.

Light, pure and colorless, as it is given to us, is susceptible of divisibility. Nature does this for us in a most complete manner in the rainbow. Artificially this is done by the triangular prism, giving us the seven hues once known as the primary colors.

The principle which underlies this experiment is this: the different

hues have different rates of vibration and different angles of refraction. The prism receives the ray of white light and, refracting it, breaks it up into its component parts, throwing the different colors at differing angles, and consequently at varying distances, upon the screen. Following up the result thus obtained led to the discovery of the spectroscope by means of which the component parts of the blazing sun and the light from the fixed stars are as perfectly analyzed and recognized as if manipulated in the laboratory of the chemist.

The solar spectrum shows peculiarities aside from colors which, like these, do not extend the entire length of the image on the screen. Beyond the rays which are there visible to the human eye, where all seems colorless and dark, at the one extreme of the spectrum rays powerful for chemical effect are found by the photographer and the chemist, while beyond the opposite or red extremity are found invisible rays of excessive heating power.

The ultra-violet rays, which to us are opaque, have, by late interesting experiments by Sir John Lubbock, proven to be less opaque to some classes of insects, than even the yellow rays. We can have no conception of what the ants see in that portion of the spectrum.

Light vibrations, like those of heat and sound, may be deflected from their course. We see the sun, a star, or a candle by its own light, which reaches us in a right line from its source. Were it not for reflection, the light of the sun would be entirely shut off wherever a shadow now exists.

Echoes are illustrations of the reflections of sound vibrations. The long rolling thunder in a summer storm, succeeding a flash of lightning from one of nature's condensers, is but the reverberation of sound waves, hurled back and forth from cloud to cloud until silenced by absorption.

The tone of an engine bell, or the whistle of the train you are passing on a railway, rises rapidly to a higher pitch as the trains approach and sinks again as they separate. The diminishing distance in the first instance increases the number of vibratory waves that strike the ear in a given time, while the receding trains diminish the number impinging upon the listener's ear during the same period, and the pitch of the tone we know depends upon its rate of vibration. The tone of a steam whistle is often varied by the engineer, who gradually opens and closes the valve, thus increasing the vibratory rate or

decreasing it, sometimes carrying the whistle tone nearly or quite through an octave.

Vibrations may be absorbed. It is to this fact that we are indebted for the hues of all nature's beauty by field and hill, by glade and stream, where but for this provision all would be tiresomely similar and sombre. This peculiarity of vibrations is made available by musicians in the use of the soft pedal of the piano and the mute on the cornet. In the acoustic telephone you all know how carefully the sound insulators must be adjusted to prevent the deadening of the vibrations and so make even a tolerable success of it. Heat vibrations are readily disseminated and dissipated by absorption; vibratory waves moving rapidly or slowly according to the relative capacities of the source and the recipient.

Some recently published results of experiments by that eminent scientist, Chas. W. Siemens, with the electric light as an aid to vegetation, are interesting from this point of view.

These experiments extended over a period covering considerably more than a twelvemonth, both inside a greenhouse and in the open air. It soon became apparent that the open air plants, which received the light rays through the glass forming the frame of the lamp, were far more thrifty and in better general condition than those under cover which were exposed to a naked light.

The first attempted explanation of this fact was the assumption that the increased production of nitrogenous and carbonic compounds was in excess of the needs of the plants, and so acted destructively. All attempts, however, to remove the difficulty, by ventilation and otherwise, proved futile. Finally a clear glass globe was placed around the light and an almost marvelous change occurred in a single night. A sheet of glass was then placed so as to intercept the rays from one portion of the plant, while other parts of the same plant received the free rays. In twelve hours a distinct line of demarkation showed where the two sets of rays joined—and yet this difference was only the result of the interception of a thin sheet of clear, uncolored glass. So far as the eye could detect no light was absorbed, nor was its color perceptibly changed, and yet a decided advantage was gained by passing the rays through this thin transparent medium.

Following up the hint thus arrived at, the learned investigator arranged the conservatory so as to submit different portions of this to

the action of light transmitted through blue, red, yellow and transparent glass, and the uninterrupted rays direct from the lamp.

Under the clear glass the most satisfactory growth was induced. Next in the order of success came the yellow; the red light produced a spindling growth with sickly yellowish leaves, while the blue exaggerated these results; and the naked light, least successful of all, produced a dark and partly shriveled growth of foliage.

Now, in all these experiments, to the absorption of invisible rays, the arresting of the vibrations of some part of the beams of light from the electric arc, are due the curious and marked results obtained.

The air surrounding us is in constant vibration. Heat, light, sound, are constantly disturbing and varying its condition. The sound of my voice, originating in a muscular movement of the throat, is carried by the wave motion there communicated to the air, and thence to the uttermost parts of the room, with comparatively little effort. Yet, in doing this, I am effecting a sensible mechanical result on a gaseous body exerting a mechanical pressure of fifteen pounds to the square inch in every direction. These vibrations are sufficiently low in their rate of movement to produce an effect on the auditory nerve of the human ear.

Man has been classified by some satirist as a "two-legged, boasting animal," and education has taught us to believe that the human race is superior, in every respect, to the so-called inferior creations of nature. We claim to be nearer, in every way, to the great Creator of the world, and highest in the scale of God's handiwork.

We are saved from mortification and exposure by the fact that the power of speech, that is language which we can interpret, has been denied to the rest of the animal world. Could they but speak to us in our language, or could we but translate theirs, they would tell us of sound vibrations so rapid that the dull ear of humanity is incapable of receiving them.

The range of vibrations which are appreciable to the human ear is limited between sixteen and forty thousand per second. That is, a vibration which completes sixteen cycles in a second, or more rapidly until it accomplishes forty thousand in the same period of time, is, save in anomalous instances, appreciable to the human ear; and these limits embrace the rates of vibrations of all appreciable sounds. Above or below these, to man, all is silence.

With an instrument similar to the siren, specially constructed for

the purpose, Sir John Lubbock created the utmost consternation among the animals of a zoological collection and killed great numbers of insects, while no noise was heard by those standing near the instrument, nor was any disturbance experienced from its action. The rate of its vibrations required a more delicate nerve organization than we are possessed of, to recognize their presence.

Perkins, the inventor of the steam gun, without recognizing the fact, arrived at the same result, namely, the production of rates of vibration above the capacity of the human ear, in the course of his experiments with steam in a high state of tension, from the standpoint of the phenomena of boiler explosions.

In a boiler of sufficient thickness and strength to secure perfect immunity from explosion, he drilled a hole not larger than a fine needle. He applied gradually increasing heat beneath this boiler until it reached the highest point attainable by the means at his command. As the heat increased these phenomena presented themselves in the order named. At first, vapor exuded from the minute orifice, then white, followed by blue steam, accompanied by hissing, succeeded by a low whistle. The sound increased in both force and shrillness, rising finally to an almost deafening shriek which the experimenter says could be heard a mile. Then the sound grew gradually fainter until silence ensued, the quantity of visible steam decreasing until neither sound nor steam were appreciable, but the circumference of the orifice became hotter and eventually assumed a bright cherry-red color. The rate of audible vibrations had been passed and some of these were now being reconverted into heat in their passage. The source of heat was now removed and the various results were again arrived at, but in an inverted order of succession.

Had Perkins been investigating vibratory law, instead of boiler explosions, he would doubtless have seized upon these capital illustrations of the conservation of energy.

His theory of the silence and the non-issuance of steam at the point of greatest pressure was, that the heat had, by expanding the steam particles, so enlarged these that they were unable to pass the orifice which had become partially closed by the expansion of the metal surrounding it.

The human eye compares no better with those of a lower animal creation. The birds, many of them, and especially those of the family to which eagles, hawks and vultures belong, are furnished with

telescopic eyes, by which variations of distance—to what extent we know not, but we do know they are great—are almost instantaneously compensated for by focal changes in the eye.

I have seen a hawk dive from the top of a high tree and seize a mouse upon the ground quite near me, before the latter could reach a hiding place ten feet from its nest which I had just overturned; and yet from that bird's lookout to me was a distance so great, I much doubt if I could have seen a squirrel to recognize it with certainty.

Some one has said, in substance, of the human eye, that it answered very well for want of a better, but that an optician who would call attention to a specimen of his work which combined so many imperfections as the the best human eye always includes, would lose, rather than gain by his advertisement.

The "eyes of science," as Proctor has so aptly designated those optical appliances, the microscope, the telescope, the camera, and others, are far more perfect in many regards than those combinations of lenses nature has furnished to humanity. The human eye is impressed instantly, but it ordinarily requires about one-sixth of a second to lose the perfect impression of any object, and this persistence of vision blurs by interference the next subsequent impression.

A meteor in the sky is to us, in its rapid movements, a luminous line, while we know that its form is globular. A sky-rocket produces much the same impression, and a fire-wheel, after its pyrotechnic fires are extinct, still shows a ring of fire, while its motion is dying down, if the case has but a spark upon it. Sparks from burning charcoal, or from a chimney, are streaks of fire; and a discharge from a Holtz machine, like that from one of nature's larger accumulators, is ever a streak of lightning. The spokes of a carriage-wheel are blended in rapid motion and the wheel assumes the appearance of a disc, while the action of a horse, at a rapid pace, is never well defined by the retina, except where an instantaneous illumination is followed by absolute darkness. Yet the camera of the photographer is competent to catch and preserve the attitude of the swiftest moving animal. Perfect representations of the fleetest racers have been thus secured with a plate exposure of such short duration that the entire animal has been pictured in the air, not one foot touching the ground.

Photographs of the sun have latterly been taken so nearly instantaneously as to show details impossible of procurement by any other method, and which, of course, had never been known before.

And the eye of science is equally superior to the human organ in other important regards. Without wearying, without even winking, it will hold its unflinching gaze, as in the case of photographing nebulæ, where two or three hours are required to fix an impression of these faint bodies; and this, too, while most ingenious apparatus is required in combination with it to compensate its visual direction for the complicated movements of the earth, during the long exposure.

In various portions of the world are found caves, the waters of which are inhabited by sightless fish—creatures possessed of only rudimentary eyes—in other words, so imperfect is their visual organism that to all intents and purposes they are totally blind. The light of day never reaches them, yet they are capable of finding their proper food, escaping from danger, hiding or fleeing when pursued; in short, accomplishing their fish destiny in much the same manner and apparently with as much success as their more fortunate and higher developed cousins in the waters above ground.

Some experiments made with specimens of these fish showed interesting results. They were confined in an aquarium in which was placed a considerable quantity of ragged rock, selected and arranged to form the best possible dark-hiding places and thus adapt their forced existence, as nearly as might be, to their natural requirements.

It was noticed that in all their movements they passed freely back and forth, around and among the rocks, without hesitation, even when suddenly startled by concussions, noises, etc., and they were found to be extremely sensitive to the least disturbance. Touching the water never so lightly with a broom-straw caused them to hide at once.

A fish of a different variety, but possessed of perfect vision, was procured and placed in the aquarium, when immediately a new series of phenomena presented themselves. As the strange fish struck the water, the poor blind creatures, instead of shrinking with fear and seeking a hiding place, at once assumed the offensive and gave chase to the intruder, who fled, evidently conscious of danger. It practiced all the knowledge it possessed in doubling and turning the angles and threading the intricate passages among the rocks, and was closely followed until overtaken and destroyed by its sightless enemy. In all this chase the track was never lost, the threatening projections of rock were evaded as readily by the pursuers as by the pursued, and no evidence was adduced to indicate that the one had not visual powers as perfect as the other.

Now, vibrations, in some form, guided these sightless creatures in the pursuit of the intruder. Whether those pertaining to smell, or feeling, or sound, we know not—we can only conjecture.

A blind man, one who from birth, or for many years has been deprived of sight, is to some extent compensated for his lack of vision by increased sensitiveness of other faculties; but these never reach the perfection shown in the experiment mentioned.

The brain, in the higher developed types of animate nature, we consider the seat of the mind, of thought, of that will-power which controls, through a system of vibratory nerve telegraph, all physical action. Physiologists tell us that at this centre of life action the record is made of all outward impressions.

In telephonic parlance it is a sort of central office, whence all responses are made, and to which all calls are sent. These delicate lines are no more wonderful than varied in their capacities and adaptations to rates of vibratory action, each within its own range or sphere.

The auditory nerve, divided into some three thousand harp-strings, is incapable of receiving impressions from finer vibrations than those pertaining to sound. The delicate organism of the inner ear may be injured so that ordinary audition is impossible; yet, if the little harp be intact, the proper rates of vibration may be communicated to and received by it through other nerves which lie in the immediate neighborhood. A deaf person may often be made to hear the twanging of a stretched cord or wire, one extremity of which is held in the teeth. The sound is communicated through the bones of the head to the inner ear. The audiphone held to the face or any fleshy part of the person will give no result, and it is valueless to those whose teeth are "marvels of art." Nor will the audiphone accept the lower jaw as even a passing good substitute, for the mechanical separation of this from the head bones interposes at the joint an imperfect conductor.

Pungent odors often produce marked effect upon the pneumogastric nerves, while a derangement of these latter may sometimes produce an effect upon the olfactories. In all these cases the vibratory effects are secondary rather than primary in their nature and power.

In the lower animal organisms, though no brain, as such, is found, there still exists, for all the requirements of these less perfect creations, a system of mental action by which all needs are provided for. Fear,

hunger, the baser passions, maternal instincts, etc., are all more or less perfectly developed.

Still farther down the scale we find in vegetable life, action which so closely approaches to that of sentient life as almost to obliterate the dividing line between the two. An acorn, starting on its life journey, finds itself opposed by unpropitious circumstances. The soil is unfavorable—a rock impedes its progress. The weakly little shoot, deterred by nothing, sends out its tiny rootlets, downward or laterally as the case requires, but always in the right direction, in search of the proper nourishment. The plant root is a faithful, honest commissary. Prevailing winds threaten its overthrow when the little oak has attained to more respectable dimensions, and now it displays the talent of an engineer, throwing out strong bracing roots, yet always in the proper direction, to prevent the threatened disaster.

See the fruit-bearing tree in the blooming season. Could every flower there become a perfected fruit death would inevitably ensue from the ill-proportioned weight on the boughs. What is the remedy? The tree, as if it reasoned with itself, seems to say: "I have provided for accidents which have not befallen me, and I have now a greater call upon my energies than is safe for my health and the good of my offspring." It dooms certain of the germs to destruction. There is no law against infanticide in nature, and the condemned, deprived of the requisite nourishment, wither and fall. Again and again, during the season, does the tree enact the several roles of accuser, judge and executioner, until it has decided what shall finally remain, and then the work of growth and ripening goes on swimmingly. It is true there are occasional mistakes made, more being undertaken than can be carried to a successful conclusion, or less than an average number of germs retained. In the former case the rule of the greatest good for the greatest number is adopted, while in the latter everything is done for the few; quality and perfection being the apology for meagre quantity.

Trees make mistakes as well as men, but trees have no brains.

Minute differences in vibratory rates are capable of producing most striking results. In musical tones, doubling the rate of vibration invariably raises the tone one octave, and every increase or decrease of the vibratory rate of a tone changes its pitch proportionately. But the same absolute pitch sounded upon two different instruments pro-

duces entirely distinct impressions upon the ear. Why? Because of the overtones, the combinations of minor vibrations, which are ever the accompaniment of any tone. These minor vibrations are combined in different proportions in different sound sources. A silver flute has not the same tone as one of wood, and the clarionet is unlike the violin in the quality of its tone. This quality of tone is almost endless in the variety which it permits in music. But material has not alone the control of this peculiarity of tone quality. Form has much influence. It lies at the bottom of those differences in the human voice by which we are enabled to select musical or unmusical vocal efforts. By the quality of a voice we may recognize an acquaintance in the dark, even after years of separation.

A careful study of the quality of the human voice is as necessary in the selection of a vocal band as is the quality combination in an aggregation of instrumental musicians. The fewer the number, too, the more apparent will be the want of that finer harmony, the pleasing effect of properly selected quality in the voices or instruments, if this study is neglected. Understand, I do not speak now of the ability to correctly reproduce every note, but a capacity to make these notes so produced blend harmoniously as a whole.

The finest singer, in advancing years, may, while retaining all the accomplished knowledge which education and practice have wrought, be very unmusical in vocal effort by reason of changed quality of voice.

Another marked result in music is chargeable to these overtones or sub-vibrations. Musical instruments are imperfect in their construction. Theoretically we assume that the scale is made up of a certain number of steps or tones and half-steps or half-tones, and that certain differences in the number of vibrations will produce a note or a half-note above or below a given tone. But you who have been compelled to listen to a piano or organ tuner know that he is a longer time at his work than would seem necessary were this the fact. Practically, there are a certain number of vibrations which he is compelled to distribute throughout the entire length of the keyboard, the result of which is that the tone steps are not of equal length, nor is the same number of vibrations added or deducted to produce a half-step. It is to this difference in the intervals which assigns bold, martial music to the sharp keys, while plaintive, gentler strains are found better adapted

to the flat keys. Any pianist who will play the Star Spangled Banner, for instance, alternately in two sharps and four flats will, I think, readily comprehend this difference. We are thus enabled to accomplish far greater variety in music than would be attainable were these distances between notes uniform in extent.

There are minute vibrations which result in changing the molecular distances of fluids, forcing these asunder and causing evaporation. Noxious smells are created in a somewhat similar manner as well as perfumes, and the distinctive odors of animals and insects, by which they recognize and trace each other.

It is related of a dog, who had long been the constant companion of a horse, that, being separated from the latter animal for a time, accidentally crossed his track, and recognizing the scent, immediately followed and overtook his old friend.

The fox-hound, trained for hunting, will only follow the trail of the fox under any circumstances. I have been told by an old hunter that these animals have been known to follow a fox track in a line parallel to it, many rods away, with a favorable wind blowing toward them, for long distances. This delicate appreciation of distance by the strength of the scent is something of which humanity can have no adequate conception until we are educated up to the olfactory capacity of a fox-hound.

Vibratory sensation is capable of development. Practice in the microscopist gives him a power of vision which the uninitiated little dreams of. The piano tuner will discover an inharmonious element in a musical chord, which to another would be utterly unappreciable. The tea taster will detect a shade of flavor or value between samples which to the uneducated would be precisely similar. The physician readily recognizes the odors of diseases, in some instances, when these are sufficiently concentrated, but when the vibratory antagonism of the molecules of these have separated them until there is no more than the highest homœopathic attenuation in the atmosphere, there may still remain sufficient of both quantity and intensity to reproduce the parent disease.

I may be chimerical, but I believe the day will come in the not-distant future, when the ingenuity of man, through the patient plodding of some hard worker in the still rich fields of vibratory law, will mark the rates of perfumes and odors, and tabulate the vibrations

of disease germs as perfectly as we now count the vibrations of sound and light. How this may be accomplished I know not, it lies in the dark future; but the discovery and its application will be no more wonderful than the development of the spectroscope which tells us of the fires in the sun, which names the metals in a glowing fire a hundred millions of miles away in space, which names to us in language that any scientist in any land may read—in nature's own tongue—the fuel in glowing suns sixty times larger than our own, by analyzing to-day a ray of light that left its source years ago, and which tells us whether distant suns are traveling toward or retreating from our own solar system.

Look at the record of the past hundred years, and, noting the progress of science, ask yourself if this is to-day more distant than was the telegraph, the telephone, the induction coil, or the electric light, a century ago.

One curious thought in all this study of vibratory law obtrudes itself upon our attention and is worthy of note here. Nowhere has man invented a mechanical motion which is not more or less directly a reproduction of one of nature's own. Reciprocating motion? It is found in the molecular movements of particles. Rotary motions have their prototypes in winds, in the movements of vapors, in the orbits of the heavenly bodies and in their diurnal revolutions.

The swinging bough and the waving grain are repeated in the pendulum—the true type of all excursionary motion. The Leyden jar, the condenser, and the induction coil are thunder clouds in miniature, and the electric light is but a continuous stream of lightning, while the Geissler tube contains but a pocket sample of the Aurora Borealis, put up air-tight for home consumption.

Vibratory law lies at the very bottom of all vegetable and animal life. To it we are indebted for all that is beautiful, in art and in nature. It gives us all our magnetic and electrical action. It actuates our telegraphs and our telephones, the fire-alarm and the electric light. Our batteries would be powerless without it. Nay, more; without these minute movements, which pervade the entire universe, there would be neither heat, nor light, nor color. The stars would cease to shine and the sun would be a blank, invisible. The earth would refuse to move; all sound would cease; darkness and death and chaos would instantly succeed to the present beautiful creation.

REPORT ON EUROPEAN SEWERAGE SYSTEMS, WITH SPECIAL REFERENCE TO THE NEEDS OF THE CITY OF PHILADELPHIA.

By Rudolph Hering, C.E.

(Continued from page 376.)

VIII. Management and Cost.

The branch of the subject which is still left to be considered is one of no less importance than the design of the works. For, although well planned, these may yet fail to accomplish their object, if not properly executed or systematically inspected and cleaned. And likewise, good designs may become entirely impracticable by being too expensive for the locality.

I therefore made inquiries also into the management of the sewerage works in other cities and their cost, the general results of which are embodied in the following.

(*a*) Management.—Under this head it becomes necessary to speak of the municipal organization in general, pertaining to the sewerage works, then of the regular service for maintenance, and finally of the execution of new works. I shall first briefly glance at the departments having charge of the sewerage.

In London all public works of a general nature are conducted by the Metropolitan Board of Works, an elected body of 45 members. All main and intercepting sewers are designed, built and maintained under this board. Branch sewers are built and maintained by the engineers and surveyors of each of the various districts into which the metropolis is divided, but all plans must previously have been submitted to the Board for approval. The corps of the Metropolitan Board consists of 20 engineers and draughtsmen, and 174 inspectors, flushers and sluice keepers for the main drainage works.

In Paris all public works are under a Director General with a general office and a corps of twenty-six persons. Besides, there are six departments, each one having a chief engineer and a large corps of assistants. The one concerning us here, and which is charged with the water supply and sewerage, has a corps of 211 engineers, more than half of this number attending to the sewerage in its design, construction and maintenance. This branch is under a chief engineer, a con-

sulting engineer, a special engineer for construction and maintenance, and one for the disposal of the sewage.

In Berlin each department is headed by a chief engineer responsible to the municipal council. The design and construction of the new sewerage works are under a special and temporary department; their maintenance is under a permanent department.

In Vienna all public works are supervised by a Director General, each department being under a chief engineer. One department is charged with designing, constructing and maintaining the works connected with rivers, canals and sewerage.

Hamburg has its public works controlled by a Building Commission, consisting of three members of select council and ten private citizens, the chairman being salaried. The department for engineering has charge of streets, parks, bridges, sewers and surveys and is headed by a chief engineer, assisted by a large corps of engineers.

In Frankfort the sewers are designed, built and maintained by a special department, headed by a chief engineer.

In Liverpool the streets, sewers and the registration of property are in one department under a city engineer. He has a special corps for the design, construction and maintenance of the sewers and inspection of house drains.

In the smaller cities the city engineers usually have charge of all public works.

It will be seen from the organizations in the largest cities of Europe that with two exceptions, Berlin and London, the sewerage works in their design, construction and maintenance are in charge of "one" department. In Berlin the special department for design and construction will be continued only until the principal works are done, after which it will cease to exist. In London the enormous extent of the works makes it expedient to allow smaller sewers to be built and cleaned by district boards.

The practical importance of placing the care and maintenance of sewers in the same department, if this is permanent, in which they are designed and built, has been fully recognized in all of the cities. The responsibility regarding the continual good condition of the works naturally causes them to be designed and built in the best manner, so that they may be readily kept in good order.

In Philadelphia the responsibility is much divided. The sewers are all designed in one department, and are maintained by another. The

main sewers are built by the department designing them, and the branch sewers by the department maintaining them. The inlet-basins are designed by one department, built by another and cleaned by a third. The lines and grades for new work are given by a fourth body, the district surveyors who are elected by and are responsible to the people, while the three departments mentioned are responsible to councils.

However well the services of each body may be separately performed, it cannot be doubted that the absence of some controlling unit must necessarily permit of great incongruities in the final result.

A department which is required to keep the works in order and which has opportunity to observe their defects and incompleteness is in a better position to judge of how they should be designed than if it is required simply to design and not to maintain, nor even regularly to inspect them.

It can hardly be doubted, therefore, that we would be greatly benefitted if the responsibility with reference to our sewerage were more concentrated than it is. The works may be well built when transferred to the department charged with their maintenance, yet if their design is such that they are exceedingly difficult to keep clean it is not very surprising that with only ordinary care they should soon get into a permanently bad condition.

The other point to be observed in the European cities is that there are permanent and trained corps for regularly examining the sewers at fixed intervals, to ascertain whether they are in perfect order or not, and to thoroughly clean them, when necessary, in the most expedient manner. Flushing with the sewage itself is the most common method for cleaning, and requires a systematic regulation of the duties of the men and but a small additional expense for flaps, gates or penstocks. Only when flushing does not remove all obstacles is it necessary to use other means, which in some cities, as Frankfort and Hamburg, are even rarely required.

In Philadelphia this service is yet entirely wanting.

It has been abundantly proved that a system of sewers can never be satisfactory without this care. In Europe it has been found that if serious defects are to be avoided an occasional examination cannot be dispensed with, and in some of our American cities the regular maintenance of sewers is also beginning to receive attention.

According to the experience and practice elsewhere, it seems advisa-

ble, therefore, if sewers are to remain in a permanently good condition, that our city should institute an efficient system of regular inspection by competent men, together with a regular flushing or cleaning, as is customary in nearly all of the other large communities. Every sewer should be passed through at fixed and regular intervals, its condition reported, and when necessary, the deposits removed.

The last feature to be considered under this head is the execution of new work.

The main sewers in Philadelphia have lately been built in a manner which insures their perfect stability. The materials employed are good. The workmanship has also been greatly improved and may be considered satisfactory. The same cannot be said of the branch sewers. The materials used for them, although better than formerly, are not sufficiently good for the purpose, nor is the workmanship as careful as it should be. The inlets likewise are not well built, the materials are not always good, nor is the work done as carefully as their object demands.

With regard to the inspection of the building of new works a similar relation exists, partially explaining this result. During the last five years a regular and constant control has been exercised over the construction of main sewers. The branch sewers are inspected at rare intervals, between which the contractor is left to himself. The inlets and house connections are often not inspected until they are completed. A natural consequence is that the main sewers have been well built, and that the branch sewers, inlets and house connections are much inferior to what they should be.

All work is done by contract, the award being lately made to the lowest bidder with adequate real estate security, not with reference to the bidder's competency. Specifications are drawn in a manner to cover all contingencies. They require a bid per lineal foot, no matter what extra quantities of material or work may be required, thus throwing all risks upon the contractor.

The European methods of executing sewerage work I found on the average to be very different from these, and impressed me as being much superior. The materials are uniformly of the best for all parts of the work. They are selected to give strength, to give a regular and smooth interior surface and to make the sewer water-tight, as already mentioned. No less care is displayed in the workmanship throughout.

The inspection of work in progress is very efficient, there being at

least one inspector for each piece of work, however small, such as inlets, house connections and repairs. They are required to certify to the faithful performance of any contract work before payment is made therefor.

In a few cities, as Berlin, the sewers are built by day's work under immediate direction of department officers. In most of them, however, they are built by contract. The specifications, then, are concise and strict. The sewers are bid for per running foot, yard or metre, but for large work a schedule of fixed prices, established by the city, is always attached, for adjusting a variation of quantities from original estimates. Contracts are generally awarded to none but those who are known to be most competent contractors.

As the advantages gained in Europe for the ultimate character of the work by this general superiority of materials, workmanship and inspection, are so marked, I cannot too much urge that greater attention be paid to this matter in our city.

In summing up the points with regard to the execution of new work, I would offer the following recommendations: First, that better materials be used, especially for branch sewers and appendages, as already indicated in detail. Secondly, that the work be done with more reference to giving the interior a smooth surface, and to making the sewers water-tight, all of which again refers more particularly to the branch sewers, and of which the value has also been previously set forth. Thirdly, that contracts and specifications be drawn for every piece of work as comprehensively, to cover every expected feature, as done heretofore. Fourthly, that no piece of work for the city be done without constant inspection during construction, and that no payments be made without a certificate that it has been so inspected and is known to be properly executed in all of its parts.

(*b*) Cost.—Finally, it is necessary to say a few words on the subject of cost, and to inquire into the effect which the changes I have recommended would have on this very important factor.

I shall first inquire into the expenditures of other cities for both construction and maintenance, in order to see what part of the municipal expenses may reasonably be allowed for this branch of public works. A direct comparison can of course not be made, as different conditions are present in each; yet an approximate comparison will suffice.

On the whole, I found that the average expense per foot of sewer

was about the same as in Philadelphia, not considering that the price of our labor is somewhat higher. The average cost of our sewers since consolidation has been $5.21 per foot, including mains and branches, and excluding street inlet-basins, whereas in Europe the general average under similar conditions, for the total works is nearly $6.00 per foot.

Regarding the annual cost of maintenance, our expenses have been as follows, including repairs and excluding the cleaning of inlet-basins, which is done under the Board of Health in connection with the street cleaning:

1874,	7·0 cents per foot.	1878,	12·0 cents per foot.
1875,	12·7 " " "	1879,	11·0 " " "
1876,	11·8 " " "	1880,	3·6 " " "
1877,	13·4 " " "	1881,	2·8 " " "

In Europe the entire annual expense for maintenance in all of the largest drained cities, excluding the pumping of sewage, is as follows, the amounts varying imperceptibly in different years. And it must be added that in these cities the sewers are kept very clean, so that walking through some of them was not found at all disagreeable.*

Paris,	13 cents per foot.	Hamburg,	3½ cents per foot.
Vienna,	9 " "	Frankfort,	3½ " "
London,	6 " "	Liverpool,	3 " "
Berlin,	4⅓ " "		

To properly compare these figures with ours, it is necessary to state that while in Europe the proportion of the above amounts spent for repairs is insignificant, in Philadelphia it averages more than three-fourths of the entire expenditure for maintenance. The amount used for cleaning alone is difficult to estimate, but it will hardly be more than two cents per foot. While this fact shows the effect of inferior construction, it also shows that we devote much less money to cleaning than in Europe. And if we couple with this the fact that our sewers, as previously indicated, are exceedingly difficult, and therefore, comparatively costly to clean, their present condition, although better than formerly, is, I think, rationally explained.

It, therefore, appears, generally speaking, that in Europe about the

*In Paris it is common that strangers, ladies included, make trips through the sewer. In Hamburg, the Crown Prince of Germany a few years ago took a trip of several miles through the largest sewer (ten feet in diameter).

same amount is paid for the construction of sewers, but a much greater amount for their maintenance, *i. e.*, cleaning.

In order that our own works may be of a similar standard of efficiency it, therefore, ought not to require the expenditure of more money per foot for new works, except, perhaps a slight increase for the difference of wages; but it would necessitate a greater sum for cleaning sewers, the expenditure of which cannot possibly be done without, if sewers are to remain in a sanitary condition, as I endeavored to show at another place.

Among the European cities just mentioned, London and Vienna mostly resemble Philadelphia, as far as the design of the sewers is concerned, and the sum there required for cleaning will be a guide as to what might be necessary here. London spends six cents per foot per year, but has abundant flushing facilities. Vienna spends nine cents per foot per year, and has no such facilities, the sewers at present being cleaned by manual labor, as here. Applied to Philadelphia these figures would represent $60,000 and $90,000 per year respectively, whereas $92,367 per year is the average yearly cost of maintenance in our city for the last eight years, including cleaning and repairs of sewers and excluding the cleaning of inlets.

With greater care in the design and construction, as has been suggested, our repairs to sewers, which make up the greatest part of that amount, would soon diminish and the proportion required for proper cleaning could be correspondingly increased, so that the total sum would not become greater than heretofore, but possibly even less, as shown.

As these are the conclusions arrived at from a general point of view, it remains to see whether they will also hold good when considered more specially with regard to the separate recommendations contained in the previous parts.

Passing over the house drainage, which is paid for by the owners, to the street-inlets, the suggestions there contained will not increase the cost beyond what would be necessary to build the present designs with the necessary care. It might even be diminished, as far as they could be more sparingly put in at the highest and lowest points of the drainage areas, and also as far as their design can be simplified. In the case where two inlets were recommended at a corner instead of one, the increased expenditure must be charged to the avoidance of the

objectionable features at a crossing, occassioned by a single inlet, and be considered as a local matter only.

Further, in discussing the sewers, it was noted that by changing their form from a circular to an egg-shape, a decrease in the width of excavation is obtained, and in many cases, where a small brick sewer is built three feet in diameter, for the only reason that it may be passed through by workmen, the egg-shape also gives a decrease in the amount of brick-work, both of which tend to reduce the cost below that of the present sewers.

When next considering the proper sizes it was concluded that pipe sewers should be laid wherever practicable in place of building three feet sewers, which also, besides making a superior sewer, somewhat reduces its cost. It was further concluded by conforming to the methods elsewhere adopted in proportioning the sewers with reference to the rainfall, that our largest sewers can be very greatly reduced in size without making them less efficient. In the special case cited, *i. e.*, the Mill creek sewer, it was concluded that a twelve foot sewer would answer fully the place of the twenty foot sewer. In calculating the difference of cost this represents it will be found to be no less than $10 per foot, or over $50,000 per mile.

A similar proportion of saving might be effected in the main sewers in all of the larger drainage areas in our city which are yet to be built.

A corroboration of this feature is given by an eminent American engineer,* who arrives at similar conclusions from his own experience with the sewers of Brooklyn.

By adopting a more rational system of proportioning sewers, therefore, and one which is endorsed by the best authorities, a considerable saving of expense can be effected, which I feel confident will fully compensate the additional expenses which should be incurred to make our system more perfect, and which I shall now mention.

The proper and careful construction of junctions, connections, etc., of sewers, were found to be of greater importance in maintaining them in a good condition than commonly supposed, and a slightly greater expenditure in making ours more perfect is well placed; for instance, by building tongues at junctions, by using cast-cement or terra-cotta blocks for house connections, and by other slight but telling improve-

*J. W. Adams, Sewers for Populous Districts, 1880.

ments. Similarly the appendages to the sewers may profitably receive greater care, the most important in this respect being the gradual introduction of flushing gates, by which the sewage is penned back for a short time, and on being suddenly released flushes the sewer. The expense of these gates, however, is itself more than repaid by the saving effected in the employment of hand labor for cleaning the sewers. Likewise will the expense of having catch-pans or basins in man-holes, to prevent street-dirt from dropping into the sewers, be repaid, for the same reason that the present catch-basins at the street-inlets compensate for their cost.

The recommendations made with regard to the details of alignment embody features which again decrease the expense, besides making the sewers more efficient, such as the early concentration of sewage into mains, and as the placing of small sewers near the gutters of wide streets.

A not inconsiderable saving can also be obtained by adopting the separate system in parts of Germantown and Chestnut Hill, in building sewers for sewage alone and allowing the rain-water either to flow over the surface or in shallow channels to the nearest creek.

It is now in place to indicate how much the cost would be affected by a better execution and management of the works. Without positive figures, of course, no positive results can be obtained, and I can only speak of this point in a very general way.

The greater expense caused by a better class of material and a more careful workmanship will be slightly decreased by the feature that the greater degree of smoothness, by increasing the velocity, admits of a smaller sized sewer. Pipe sewers, up to 15 inches diameter, cost less than three feet brick sewers, both being equally well built.

Again, the greater expense of a more thorough inspection of the building of our works will be compensated by the superior grade of execution attained thereby, not only by causing a more efficient sewer in its operation, but also by preventing the large number of breaks, the repairs of which have yearly required an extraordinarily large sum of money. But even if better sewers would be more costly, their sanitary importance, I trust, would fully justify a small additional expense.

Also, a more concentrated organization for our sewerage works, as suggested in place of the present divided responsibility, would tend rather to decrease than to increase the expense of supervision, design

and maintenance, if public work and private work are to be judged in this respect on a similar basis. It appears, therefore, that a better execution and management of the works could not greatly raise the present total expense for this purpose.

Anticipating that the condition of our works would demand a large expenditure of money to bring them up to a sanitary standard, the subject of cost appeared to me an important one for this city. Therefore, while abroad, I gave very special attention to all directions in which a saving might justly be effected. And I am now gratified to say that from these conclusions, as far as they can be drawn from general inquiry, there is every indication that the changes which I have seen proper to recommend, to establish a good system, such as is common in the large cities of Europe, will not, on the whole, require more money than the average amounts we have spent for sewerage during the last decennium. The greater expense necessary in some directions to make the works better, both from a constructive and a sanitary point of view, will be balanced by a less expense in other directions. To do the latter without the former, however, should be deprecated to the utmost degree, because the first and foremost object of a system of sewers is a *sanitary* one, and this should not be sacrificed even if a saving of money could be effected thereby.

Although the cost of better works would apparently necessitate no greater expenditure than heretofore, the cost of repairing and altering improper ones will be additional. But this expense cannot be done away with under any circumstances, if the sewers are to be put into a proper condition. A few thousand dollars, however, spent judiciously every year, would soon relieve the city of the effects of the most objectionable defects in our sewers.

Before closing this part, a few words must be added with regard to the cost of the intercepting sewers recommended for the future.

An early study into the alignment of an ultimate system, and its early establishment, will enable sewers which later must form essential parts to it, to be given such positions and elevations which will be suitable for the future, besides answering their present purpose.

The Manayunk sewer, which is to contribute towards preserving the purity of the Schuylkill drinking-water, requires a diameter of not over five feet, its expense will not be over $750,000. The urgency for this sewer depends on the degree of pollution of the Schuylkill by the Manayunk sewage.

The sewer proposed to intercept the south-western slope of Germantown and to carry the sewage to the West Cohocksink basin requires a diameter of less than four feet, and would cost for a length of four miles about $125,000, a large part of which would be covered by the usual assessment on properties. The urgency of this sewer will depend on the necessity for preserving the purity of the Wissahickon creek.

The northeastern slope of Germantown is now drained into the Wingohocking creek, which subsequently discharges into the Frankford creek. The intercepting sewer suggested to prevent the Germantown sewage from polluting the Frankford creek, which can never be sewered, and should, therefore, always be kept as pure as possible, begins at Wingohocking creek where the North Pennsylvania Railroad crosses it, and can discharge temporarily into Hart creek sewer. Its length is about one and three-quarter miles, the diameter would be about five feet, and its cost about $90,000. The necessity for this branch of the general system of interception would arise, when the pollution of the Wingohocking creek and Frankford creek by the Germantown sewage is considered objectionable.

The remaining intercepting sewer, which may seem necessary at no distant day, is the one which prevents the sewage from flowing into the Delaware river docks between Kensington and the old Navy Yard. An approximate estimate of its cost, however, can not be made without a more detailed study than I have given it.

IX. Recapitulation of General Conclusions.

I shall now conclude my report by reviewing the main points which, from my inspection and study, I believe to be of most importance as far as the needs of Philadelphia are concerned.

In order to get as complete an understanding of the subject as possible, I visited every city in England and on the Continent where any pretence was made of having a good or instructive system. Nearly all of the cities showed works greatly superior to our own. The designs were, as a rule, carefully conceived in accordance with engineering and sanitary principles. The construction, too, received more care, in the selection of materials, in the workmanship, and in the inspection. The maintenance of sewers, to which as yet but little attention is given in this country, except in a few cities in New England, is carried on in every city by a well-trained corps, which

regularly flushes and cleans all the sewers at frequent and fixed intervals, so that I did not find an objectionable condition in any system or part of one claimed to be good, even when selecting my own points where to enter and examine them.

To render the Philadelphia sewerage works equally efficient, from a sanitary and economical point of view, it will be necessary to alter and improve the designs and the construction, and to institute a regular system of flushing. In what special directions these improvements should be made I have indicated under the corresponding heads. I shall simply restate them as briefly as possible.

In view of the several systems of city sewerage which are advocated at present, and of each of which I examined the best examples, my conclusions are that different parts of the city will be best served by different systems. For the greatest portion of our city the one which is or will be closely built up during the present generation, the so-called "combined" system, leading sewage and rain-water into the same channels, is the preferable one. For suburban districts, which are not likely to become densely populated, the so-called "separate" system, by which the sewage is led into sewers and the rain-water either into a few special and shallow channels or entirely over the surface, is to be preferred, because it is as efficient for such localities and much more economical. Should any of these suburbs ever become closely built up, it also in no way prevents the gradual addition of subterraneous rain-water channels as needed from time to time, thus forming a complete separate system.

Under the head of house sewerage, it is suggested that cesspools or wells should be deprecated and as much as possible abolished. Municipal regulations regarding the house drainage should be adopted, following in this not only many European but also some American cities.

The parts of the system receiving and discharging the street water into the sewers—namely, the "inlets"—should be built so as to insure a water-tight basin and an effectual trap. They should be placed, where possible, above the sidewalk crossing instead of at the corners, in order to avoid the objectionable gutters—a custom which is almost universal in Europe. The "necks" should be of vitrified pipe, instead of two-foot brick sewers, in order to avoid deposits and retention of foul matter in them. Further, inlets should be placed as sparingly as possible at the highest and lowest parts of drainage areas, where they are seldom justified.

The sewers themselves were next examined into and the following conclusions arrived at: Regarding the proper shape to be given to them, it was shown theoretically and by the long experience in Europe that none but an egg-shape will conform to the requirements of a sewer of the combined system, and that our custom of building them circular is one of the main causes of our troubles. For intercepting and pipe sewers only the circular shape is the best.

Regarding the size of the sewers, it was found that essential improvements could also here be made. In the absence of observations showing the effect of storm-water in our sewers, the obtaining of which is urged, the experience from many European cities was collected, examined and compared with American experience, and the results applied to our own conditions. This revealed the fact that if our small sewers are correctly proportioned, the largest ones are entirely too large; and if the latter have a proper size, the smaller ones are too small. The first case, however, is nearly the true one, regarding storm-water removal. That the reduction of size obtained thereby is a matter of great economy will be self-evident, and that it is also one of sanitary benefit, in the better conveyance of the sewage itself, is a point acknowledged by all sewage engineers in Europe, and has recently, by an extreme case, also been shown in Memphis, Tenn., in the system designed by Col. Waring. Quite contrary to a common opinion that our sewers are too small, there is no doubt that an essential source of trouble is caused by their often being too large. The superiority of well-laid pipe sewers over brick sewers is likewise alluded to.

The grades are next considered and the proper limits indicated. The practical importance and economy of distinguishing between dry-weather and storm-water flow near outlets into tidal rivers is also shown.

Finally, it is urged to give more attention to the construction of branch sewers, after mentioning the great superiority in the materials and workmanship employed for this purpose in Europe and the advantages which accrue therefrom. Besides giving sewers more stability, the walls should be made water-tight and the interior surface as smooth as possible, to prevent retention of filth. When it becomes necessary to alter the most objectionable of the three-feet sewers, it will generally suffice simply to re-form the invert with concrete, instead of rebuilding the entire cross-section.

A more careful consideration is then recommended to be given to

the proper designs for sewer junctions, house connections, storm-water overflows and sewer outfalls into the river, with a view of avoiding any retention of matter by eddies and backwater—points which in Europe have received much greater attention, and the importance of which is fully set forth.

The various appendages to sewers to facilitate their inspection, their ventilation and flushing are then examined, the most efficient plans customary in Europe indicated, and the special features emphasized which are applicable to and advisable for our own conditions. It is found that the only effectual and economical mode of ventilating sewers, after many trials and long experience, is by gratings in the manholes placed in the middle of the street, and by soil-pipes when they are built of iron with leaded joints and carried above the roof. It is further found that flushing with sewage itself, as practiced in nearly all large cities of Europe, is not only effectual in removing all ordinary deposits, but it is the most economical method.

In order to attain these benefits, however, it is necessary to improve several conditions simultaneously. A regular inspection of our sewers becomes impracticable without a good ventilation for them. The latter, when obtained through openings into the streets, is often objectionable, unless the sewers are regularly flushed and built with a smooth surface and otherwise in accordance with the principles previously stated. Flushing, finally, cannot be effectual without appliances therefor and a systematic service.

Several points are then given with regard to the alignment of sewerage systems. Valley line sewers were used wherever no difficulty was experienced in having a natural outfall. Intercepting sewers were used to prevent an undue accumulation of rain-water at the foot of slopes, to prevent sewage or rain-water from flooding low districts, and the former from flowing into the rivers and docks in front of a city. Attention is called to the fact that early concentration of sewage into a few larger channels is more economical than to collect it more uniformly from the area.

An inquiry into the ultimate disposal of the Philadelphia sewage revealed the fact that purification is not necessary, and that the Delaware river is sufficiently large to receive it without the danger of causing pollution. It will become necessary, however, to prevent a deposit of filth and silt along the wharves, by carrying the sewage either into

the channel by a few submerged conduits, or by an intercepting sewer to a point below the city.

I have then proposed a system of intercepting sewers, which, in its general features, seems to answer present and all future requirements, and which conforms to the principles tested and practiced in Europe. It has also the advantage that small portions can be built to relieve certain sections from time to time as required, and of being uniform in its entirety and making a complete and economical system in the end. The sewers which would be among the first to require construction are those preventing a pollution of the Schuylkill river from the Manayunk sewage, the Wissahickon and Tacony creeks from the Germantown sewage, and the docks along the Delaware river from the sewage of the older part of the city. A close study into the adoption of some ultimate system is urged, so that works hereafter built may conform thereto and future rebuilding become unnecessary.

The question of the management of sewerage works is then entered into, and after indicating the organizations for this purpose in all of the large European cities, it is found that the designs, the building and maintaining of the works, are placed under one head, while in our city the responsibility is divided among four distinct bodies. A greater concentration could not be otherwise than beneficial here, as it is in Europe.

It is then recommended to gradually institute a system of regular flushing, the best and most economical means by which a system of sewers can be kept in a sanitary condition. Also, that no part of the work be done without a constant and competent inspection.

The last part of the report contains an inquiry into the effect which the foregoing recommendations will have upon the cost of the works. From a general comparison between expenses in foreign cities and our own, it is found that we spend nearly as much for new works per running foot under similar conditions. In comparing the cost of maintenance, it is found that the city whose sewers most resemble our own—Vienna—spends nearly the same amount per foot, and that London, which stands next in resemblance, spends about two-thirds of our amount, but has complete flushing facilities. From this general comparison, therefore, it would seem that the sewerage works in our city, in order to be efficient, should not require much more money, if any, than heretofore. And this is confirmed by a detailed inquiry.

With regard to new works, it is stated that an increase of expenditure

would be very desirable and beneficial in the direction of improving the designs of junctions, house connections and manholes, and in bettering the standard of the materials and workmanship, particularly for branch sewers and appendages. On the other hand, it is found that a relative decrease of expenditure can be obtained by building egg-shaped and pipe sewers, in place of three-feet circular branch sewers, where the capacity admits of it. Further, a very large saving of expense is gained by a more rational proportioning of the sizes of sewers, and by adopting the separate system for certain outlying districts. New works, therefore, when designed and built as recommended, need not, on the whole, require more money, apparently, than when built according to present customs, the exact relation to be determined only by a detailed and local estimate. The increased cost for more thorough inspection of new works will be fully compensated by a decreased cost of repairs. In Europe the necessary repairs to sewers are quite insignificant, and in our own city the sewers which had a constant inspection during their construction have so far cost nothing for repairs.

The maintenance of sewers requires the additional expense of flushing gates and penstocks, but the saving of hand-labor effected by them in removing obstructions much more than pays for their cost. The proportion of our average yearly expense for maintenance devoted to repairing breaks or defective sewers, is estimated to be over three-fourths of the entire amount. When the sewers are better designed and built under inspection the repairs must become less and less. If the amount of money thus gradually saved is devoted to a more thorough cleaning and flushing, the sanitnry condition can be improved without greater expense than needed heretofore. And if the comparison between Philadelphia, London and Vienna is taken as a guide, the same average cost of maintenance which has been required during the last eight years would in future be sufficient to keep our sewers as clean as those in Europe.

When it is finally considered that a greater concentration of authority could not greatly increase department expenses, if at all, it seems to be clearly indicated that also a detailed inquiry into the changes recommended leads to the same conclusion which was drawn from a general comparison with European expenditures.

Before closing I desire to state that during my visit to the various towns I was impressed with the fact that the design and maintenance

of city sewerage, if it is to be a sanitary work, requires more skill and attention than is usually given to it in our own country, or even thought necessary. And herein lies a fundamental reason why so many works are in an imperfect condition. The best sewered towns in Europe were designed and managed by specialists in this branch of public works. Nothing short of a careful study, therefore, could reveal the features which were best adapted to the requirements of this city.

With the hope that this report may fully cover the required points and may contribute towards the improvement of an important branch of the public works of our city, it is respectfully submitted.

Excess of Labor in Schools.—In a large establishment, containing about 600 children, half girls and half boys, the girls were found to accomplish an amount of labor greater than that of the boys. At each inspection it was observed, with surprise, that they were more alert and better developed; and yet the girls were in school only eighteen hours per week, that is to say upon alternate days, while the boys had thirty-six hours per week. Afterwards, when the boys were submitted to the same rules as the girls, their work was much more satisfactory.—*Les Mondes* C.

New Cometary Theory.—Prof. C. Schwedoff, of the University of Odessa, regards the tails of comets as simply luminous phenomena. The nucleus of the comet, in traversing the æthereal medium in the manner of a projectile would produce at each instant, by the compression of the æther, a luminous wave. The trajectory traversed by the nucleus should then be considered as the geometrical locus of a centre of movable undulation, and the partial waves, emanating successively from the different points of this trajectory, would give, on superposition, a resultant wave which would be the cometary form itself. Schwedoff calculates the comparatively simple case of the section of the wave by the orbital plane, that is to say, the form of the comet for an observer placed at an infinite distance upon the normal of the plane. He thence deduces the possible existence of two types of tails. His theory reduces the study of cometary forms to the discussion of a mathematical formula, and thus merits the attention of astronomical geometricians. Observation alone can decide whether it has a sufficient physical foundation.—*Ciel et Terre*, June 1, 1882. C.

Explosion of Carbonic Acid.—L. Pfaundler placed a sealed glass tube, which was about two-thirds full of liquid carbonic acid in a bath of carbonic acid and ether, which had been reduced to a temperature below —100° (—148°F.), in order to obtain crystallized carbonic acid. Beautiful, transparent, strongly refracting crystals soon appeared, which completely filled the submerged portion of the tube, while a layer of fluid carbonic acid floated over them. After a few minutes the upper end of the tube, which was exposed to the air, suddenly exploded with a loud report. The same tnbe had previously been often exposed to a temperature of more than 31° (55·8°F.) It is possible that the glass, at this low temperature, became so brittle that it could not bear the steam pressure of the still fluid portion of the carbonic acid and the influence of the temperature of the air. But it seems more likely that the solid carbonic acid burst the tube in consequence of its thermal expansion.—*Ann. der Phys. und Chem.*, 1882, p. 175. C.

The Figure of Comets.—M. Faye thinks that the combined influences of solar attraction, which tends to decompose bodies of small mass and great volume, and of solar repulsion, which begins to act on the evaporable portion of the mass which is withdrawn from all pressure and submitted to an increasing heat, are sufficient to explain cometary phenomena, without resorting to the hypothesis of an electric or magnetic repulsion. In the irresolvable nebulæ, and the manner in which they are distributed in space, he finds evidence of the repulsive action which the stars exercise over the extremely tenuous matter by which they are surrounded. The light of the nebulæ appears to him to be of exactly the same nature as that of comets. He can find no reason for attributing a cosmic agency to the electric forces which we observe upon the earth. It is true that the least chemical action, the least friction, the least contact of two bodies, sets these forces in play; but by the very nature of polar forces they soon become mutually destructive. If the globe is an immense reservoir of electricity the electricity is neutral, and it is only occasionally that the existence of the forces is perceived. It requires the genius of engineers to separate them, to conduct them to a distance, and to force them to execute their admirable works by their recombination. Beyond the globe all this disappears. The simple incandescence of the sun is sufficient to explain the phenomena of repulsion which are indicated by the gigantic tails of comets.—*Comptes Rendus*, xcv, 427. C.

Curious Observation of Comet Wells.—On the 10th of April, 1882, Prof. Zona determined the position of this comet; but at the end of the observation, he noticed that the light of the tail changed while he was looking at it. He paid no attention to this phenomenon because the sky was cloudy and his eye fatigued. On the 14th he made a similar observation, but he attributed it to an atmospheric cause, the sky being not yet entirely clear. On the 17th the phenomenon returned with more marked intensity, the sky being cloudless. The Professor called his assistant and asked him to look at the comet's tail. After some minutes the assistant said: "It seems to me that the light of the tail gradually diminishes, as if the nucleus was attracting it, and then increases, as if it was going out from the nucleus." Prof. Zona then looked more attentively, and saw that the tail had a steady but very feeble light during eight or ten seconds. Then, for about a second, the tail had luminous pulsations, after which the period of calm returned. The phenomenon reminded him of the scintillation of the glow-worm and the movements of the aurora.—*Les Mondes*, cited in *L'Astronomie*, i, 272. C.

Synchronism of Electric and Optic Phenomena.—E. Bichat and R. Blondlot have studied the rotation of the plane of polarization in a transparent body, under the action of the discharging current of a Leyden jar. The transparent body was placed between a polarizer and an analyzer, in a coil with long and fine wire, which was connected with the armatures of a battery. In the circuit was interposed an exciter, which allowed a discharge to be produced when the difference of potential was sufficient. At the moment of each discharge the eye which was placed before the analyzer noticed a vivid reappearance of light, which showed that the plane of polarization had been changed. A mirror, turning about a vertical axis, was then placed before the optic apparatus. The polarizer was provided with a slit, likewise vertical, through which the image in the mirror was observed by means of a telescope. An arrangement was made for producing the spark at the moment when the mirror occupied such a position that the image of the slit was visible in the telescope. Two systems of bands were thus observed: one due to the light of the spark, the other to the polarizing apparatus. The electric and optical phenomena were absosolutely simultaneous, or, if there was any difference, it must have been less than $\frac{1}{30000}$ of a second.—*Comptes Rendus*, xciv, 1590. C.

Subsidy to Pasteur.—The French minister of Agriculture has lately placed at the disposal of M. Pasteur a new sum of 50,000fr. ($10,000), in order to continue his admirable investigations upon the contagious diseases of animals. The government had already granted to the illustrious savant, for the same object, 50,000fr. in 1880 and 40,000 in 1881. The minister consulted a special committee who, in view of the brilliant success obtained by Pasteur in his previous investigations, unanimously recommended a renewal of the grant.—*Les Mondes*, Sept. 9, 1882. C.

Solar Cannon of the Palais Royal.—The little cannon of the Palais Royal, in Paris, which automatically notes the hour of noon, dates from a greater antiquity than is generally known. It thundered during the commune, under the empire, during the days of '48, under Louis Philippe, under the Restoration, during the wars of the Grande Armée, during the guillotines of the Reign of Terror, on the day when Camille Desmoulins harangued the people, under Louis XVI, under Louis XV. In his charming "Journey from Paris to St. Cloud, by Land and by Sea," published in 1751, Néel makes his young tourist regulate his watch by it. The pillar on which it is fixed stands at the point where, in 1641, a year before his death, Cardinal Richelieu established a bound between the manors of St. Honoré and of the Archbishopric. —*L'Astromomie*, i, 241. C.

Improvement of Marshes.—In the province of Venice there are still extensive tracts of marsh, especially in the territory comprised between the Tagliamento and the Livenza, and between the latter and the Piave, in the two districts of Portogruaro and of San Dona. These two districts include 38,000 hectares (146·57 sq. m.), besides many tracts already under cultivation, which suffer greatly from obstructions to the free flow of water. In these districts there are improvements, which have been executed by intelligent occupants, who draw large profits from them, although they have sustained the entire burden at their own expense; but they are true oases in the midst of broad filthy marshes, and serve as an eloquent proof of the great advantages which might be derived from the redemption of the fertile virgin soil. The Italian government has offered subsidies and other measures of protection and encouragement, in the hope of extending these improvements for hygienic as well as agricultural purposes.—*Il Politechnico*, xxx, 458.

Water-Spouts at Etretat.—Leon Lalanne, in a letter to M. Faye, records his recollections of an interesting phenomenon which he observed on a September morning, in 1851. Eleven water-spouts were formed in less than a quarter of an hour, before the eyes of spectators who were surprised and considerably disturbed at the consequences of the phenomenon, which was driven directly before them. Finally, without lightning, without thunder-claps, but in the midst of a gust of wind which culminated in a tempest, one or two of these water-spouts were seen to break in a deluging rain against the rocks which jutted from the western part of the beach. The spectators were soon overwhelmed with torrents of rain, accompanied by heavy squalls of wind, but without any other evil result than that of being thoroughly drenched. The occasion was remarkable for the large number of simultaneous water-spouts, and M. Faye regards it as strongly confirmatory of his whirlwind theory.—*Comptes Rendus*, xcv, 430. C.

Influence of a Polished Specular on Actinic Reflection.—M. de Chardonnet has photographed, with instruments of quartz and of Iceland spar, the spectrum of rays reflected from a variety of substances. By prolonging the exposures sufficiently he has been able to assure himself that there is no absolute eclectic absorption. He tried in succession: white enamel, black enamel, uranium glass, rough hematite, polished hematite, diamond, compressed carbon, both rough and polished vermillion, gold, lead, nickel, Arcet's alloy, copper, polished steel, rough steel, Prussian blue, green leaves, telescope metal, and mercury. Silver would seem to be an exception to the general rule, because it becomes transparent for the second half of the ultra violet spectrum; but on prolonging the exposure this region appears with all its details. Among liquids, he tried distilled water, solutions of fuchsine, of acetosulphate of quinine, of ammoniacal sulphate of copper, of bichromate of potash, milk, ink, alcohol, ether, benzine, olive oil, which all gave complete spectra. From his experiments he deduces the following laws. Every surface reflects, in variable proportions, each of the radiations of the spectrum. The reflecting power of a liquid is independent of the substances which it holds in solution or in suspension. The polished specular serves to increase the total quantity of the reflected radiations, while the relative intensity of the different regions of the spectrum, or the actinic color of the body under consideration, depends on the material employed.—*Comptes Rendus*, xcv, 449.

Franklin Institute.

HALL OF THE INSTITUTE, November 15, 1882.

The meeting was called to order at the usual hour, with the President, Mr. Wm. P. Tatham, in the chair.

There were present 149 members and 19 visitors.

The minutes of the last meeting were read and approved.

The Actuary submitted the minutes of the Board of Managers and reported that at the stated meeting held Wednesday, November 8th, 16 persons had been elected members of the Institute.

The Special Committees on Prevention of Fires in Theatres and on Memorial to Mr. Briggs reported progress and were continued.

Mr. Wm. B. LeVan read the concluding portion of a paper on "Steam Economy," which appears in the JOURNAL for December.

Mr. J. Snowden Bell inquired the author's experience in the use of heated air.

Mr. LeVan replied that when introduced above the grate he found it to be of decided advantage if sufficiently hot, *i. e.*, above 800°.

Mr. Hector Orr, referring to the author's statement of the small percentage of the thermal effect of the fuel which was utilized in the steam engine, claimed that this wastefulness was to be charged to the use of solid fuel. He advocated the substitution of gaseous fuel.

Mr. Wm. E. Lockwood asked the author's experience as to the economy of using high pressures.

Mr. LeVan replied that pressures of 200 pounds had been worked quite successfully. Higher pressures had not been found so satisfactory, mainly, he thought, because of the want of the necessary experience. He believed that the time was not far distant when the use of high pressures would be the common practice, and when 200 pounds would be considered an ordinary pressure.

Professor Wm. D. Marks made the criticism that steam economy, as the author had put it, might not necessarily imply economy in dollars and cents; that the interest and other charges in maintaining an expensive and complicated plant might more than offset other advantages.

Mr. LeVan replied that he proposed to economize by subdividing the power, using a number of small engines in place of one or more large ones. In answer to questions he further added that with respect

to engineers' wages, he believed that this item would not be greater, or that it might even be less. He did not think that there would be any increased hazard in the use of very high pressures. He believed that where there was greater risk, this was always compensated by the exercise of greater care.

In the absence of the author, a paper on the "Abstraction of Heat by Mechanical Energy," by Mr. John Rowbotham, was, on motion of Mr. A. B. Burk, read by title.

The following are the more prominent subjects mentioned in the Secretary's report:

Several forms of improved Testing Machines, designed by Mr. Tinius Olsen, were described, including one for scientific investigation made for the Rensselaer Polytechnic Institute of Troy, N. Y., capable of applying continuous strains of every description to test pieces, as well as intermittent strains. A Spark Arrester for Locomotives, invented by Mr. Rufus Hill, Master Mechanic of the Camden and Atlantic Railroad Co., and which was said to have shown itself to be well adapted for its intended uses, was shown and described. A number of views showing details of Mr. Pohl's Differential Car Starter were exhibited and described. The following inventions were also exhibited: A Friction Drive Chain, made by the Ewart Manufacturing Co. of Chicago, in which the links of malleable iron are detachable, each link having projections forming wedges which engage in a continuous groove in the pulley-wheels. A Safety Belt Mounter, made by R. P. Ashley, of Camden, N. J., after a pattern long used with success in England, and which puts taut belts on running pulleys without delay or danger. A specimen of Car Axle Brass of "Deoxydized Bronze," made by the Philadelphia Smelting Co., a very dense and homogeneous metal, with very high polish and regular surface, free from pits or blow-holes. Clapp's Circulating Drop Tube for Steam Boilers, made by the Clapp & Jones Manufacturing Co., Seneca Falls, N. Y. The tube depends from the crown sheet into the combustion chamber. Three slips of iron arranged triangularly form a partition to assist the circulation. These slips are punched with lips to assist in preventing the entanglement of water with the steam.

Dr. B. A. Watson's Lever Excision Saw, a surgeon's saw, designed to take the place of the chain saw, and claimed to be simpler and more rapid in its action; A. H. Reid's Lightning Brace, for light boring and screw driving. The power is applied at the top, enabling consid-

erable force to be applied. It may be used either by running the bit both back and forward, or by turning the bit one way only, as is necessary to drive a screw or bore a hole with an auger bit. This is done by means of a divided head, which acts as a fast and loose pulley, there being no ratchet. A series of very minute files for jeweler's use, made by Mr. Wm. Myers, of Philadelphia. A small indicator, made by the Crosby Steam Gauge & Valve Co., of Boston, and designed especially for indicating locomotives and high speed engines. A new plastic material, invented by Mr. Edward Weston, of Newark, N. J., and intended as a substitute for celluloid and for other uses. Specimens of the material, and of carbon filaments for incandescent electric lamps, made from it, were shown. The latter possessed a remarkable metallic lustre.

Dr. Bruno Terne next described a representative collection of products manufactured from animal bones, which were presented to the Institute by the manufacturers, Messrs. Baugh & Sons, of Philadelphia.

The President, Mr. Wm. P. Tatham, after inviting Vice President Frederick Graff to the chair, then described the principles of construction and mode of using the dynamometer, which he had at length succeeded in perfecting, at the cost of much study and time. In presenting the machine to the Institute he stated that the Institute was under obligations to the Isaac P. Morris Co., and Messrs. Fairbanks & Co. for having respectively furnished the pulleys, shafts, bearings, and cast iron frames and the scale work, without charge. He added that he desired a critical investigation of the machine by the Institute through a committee or otherwise, and hoped, if it met with approval, that the Institute would adopt it, and let it be known as the Franklin Institute Dynamometer.

At the conclusion of the demonstration Prof. Marks, after alluding to the importance of the elements which he believed Mr. Tatham had succeeded in realizing in his construction, moved that a committee be appointed to subject the Dynamometer to a careful scientific investigation, and to report the results of such investigation to the Institute, with such recommendations as they might deem proper to make. The motion was carried, and Vice President Graff named the following members to constitute the committee, viz: Prof. W. D. Marks (ch'n), Coleman Sellers, Washington Jones, Hugo Bilgram, and C. Chabot.

The meeting was thereupon adjourned.

WILLIAM H. WAHL, *Secretary.*